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The primary goal of the Acquisition Review Quarterly (ARQ) is to provide practicing acquisition professionals with relevant management tools and information based on recent advances in policy, management theory, and research. ARQ addresses the needs of professionals across the full spectrum of defense acquisition, and is intended to serve as a mechanism for fostering and disseninating scholarly research on acquisition issues, for exchanging opinions, for communicating policy decisions, and for maintaining a high level of awareness regarding acquisition management philosophies.

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OPINION

DOD AND THE CHANGE PARADIGM: *CHANGE AGENTS VERSUS ESTABLISHED SERVICE ROLES, MISSIONS, AND CULTURES*

J. Robert Ainsley, Ed.D. and James Riordan

Little money has been available to modernize combat forces over the past 10 years. How can the Department of Defense reengineer the defense acquisition system to provide modernization? What change agents can be applied to alter the established Service roles, missions, and cultures? The authors provide some background on the issue and look at a small segment of it—the barriers to establishing a single DoD acquisition organization and possible ways to overcome these barriers. They investigate the concept of the merger of individual service acquisition organizations into a single organization under the USD(A&T).

During the last 10 years, increased competition and reduced revenues have driven private industry in the United States to take unprecedented steps such as major reorganizing, consolidating, and revamping and modernizing business practices to remain competitive and become more efficient. To accomplish this, they have discarded outdated and excess facilities, eliminated duplication, streamlined organizational structures, reengineered processes, and overcome the strong resistance of entrenched workforces.

Although the goals of the Department of Defense (DoD) differ from the goals of private industry, DoD faces a similar situation. Budgets of both are declining and competition for resources is increasing. But DoD has not been as quick to revamp and modernize its business practices. Though DoD has downsized and has undergone some reorganization, changes to business practices have been limited to "tinkering around the edges." For example, DoD's acquisition workforce has been reduced by almost 50

percent over the past nine years, but none of the Services have significantly changed the way their acquisition commands are organized or operated.[1] As a result of DoD's failure to change the way it conducts business, there has been little money available to modernize combat forces over the past decade.

With the worldwide proliferation of military technologies, and relatively easy access to weapons of mass destruction, modernization of America's combat forces can no longer take a back seat. While many factors influence DoD's ability to successfully modernize its forces (e.g., politics, engineering practices, goals, and operational scenarios), antiquated business practices and organizational structures are two of the major factors preventing progress.

"With the worldwide proliferation of military technologies, and relatively easy access to weapons of mass destruction, modernization of America's combat forces can no longer take a back seat."

Secretary of Defense William Cohen made this point to Congress in December 1997, when he stated that the capabilities of our combat forces must no longer be "...held back by a burdensome infrastructure and outdated business and acquisition practices." To afford to modernize combat forces, DoD must follow industry's lead and totally revamp its organizational and business processes. Jacques Gansler, Under Secretary of Defense for Acquisition and Technology (USD [A&T]), pointed out in his February 1998 address to the Industrial College of the Armed Forces Class of 1998 that the only way DoD can afford to modernize weapon systems for the 21st century is to revamp the acquisition and logistics side of defense. DoD needs to undertake a "revolution in business affairs" (RBA) in order for its revolution in military affairs (RMA) to be successful. According to Gansler, the keys to the RBA are to:

- adopt modern business and commercial practices;
- consolidate and streamline DoD's acquisition and logistics organizations;
- embrace competitive market strategies; and
- eliminate or reduce excess support structures.

While few would argue against reducing excesses and embracing new strategies, there are many arguments for and against consolidating DoD's acquisition organization.[2] Perhaps the answer is not consolidating but rather reengineering the entire defense acquisition system. We do not support one side or the other. Rather, we provide some background on the issue and look at a small segment our literature search indicates has not been investigated: the barriers to establishing a single DoD acquisition organization and possible ways to overcome these barriers. For the purposes of our research, a single DoD acquisition organization is defined as the merger of individual service acquisition organizations, into a single organization under the USD(A&T).

BACKGROUND

CURRENT STATE OF U.S. DOD ACQUISITION ORGANIZATIONS

Acquisition of defense equipment in the United States is mostly decentralized. While top-level policies are established at the DoD level, each military department procures the majority of its own equipment. Furthermore, multiple acquisition organizations exist within the military departments themselves. The Department of the Army has an Army Material Command, which is subdivided into four acquisition organizations: the Communications-Electronics Command is responsible for acquiring command, control, communications, computers, and intelligence (C4I) systems; the Aviation and Missile Command, responsible for acquiring aviation and missile systems; the Soldier Systems Command, responsible for acquiring all soldier and related support systems; and the Tank-Automotive and Armament Command, responsible for acquiring munitions, armaments, and tracked and wheeled vehicles.

The Department of the Air Force has an Air Force Material Command subdivided into three acquisition organizations: the Aeronautical Systems Center, responsible for acquiring aircraft and related equipment; the Electronic Systems Center, responsible for acquiring C4I systems; and the Space and Missile Systems Center, responsible for acquiring space systems. The Department of the Navy has four acquisition organizations: the Naval Air Systems Command, responsible for acquiring aviation related systems and equipment; the Naval Sea Systems Command, responsible for acquiring ships and related systems and equipment; the Space and Naval Warfare Systems Command, responsible for acquiring C4I and space systems; and the Marine Corps Systems Command, responsible for acquiring ground systems and equipment for the Marine Corps. It should be noted that aviation-related systems and C4I systems are acquired by all three military departments and ground-related systems and equipment are acquired by at least two of the departments.

FOREIGN ACQUISITION AGENCY STRUCTURES

Many U.S. allies have consolidated their defense acquisition organizations into a single agency.[3] For example, defense acquisition for Canada is centrally conducted by Public Works and Government Services Canada. France has a General Directorate for Armaments (DGA) which procures all defense-related equipment. In Germany the Directorate General of Armaments (NAD) centrally procures defense equipment through that country's Federal Office for Military Technology and Procurement. The Chief of Defence Procurement heads the United Kingdom's centralized defense acquisition organization. A Director General in Israel's Ministry of Defense heads the Directorate of Defense Research and Development and the Directorate of Production and Procurement, which centrally manage all defense-related equipment acquisitions. In addition, Japan's Central Procurement Office

> **"Many U.S. allies have consolidated their defense acquisition organizations into a single agency."**

procures major defense articles required by the Self-Defense Force.

The mere fact that the countries we have noted have consolidated their defense acquisition activities under a single agency is by no means a testimony to the productivity of such an arrangement. There are conflicting arguments as to their effectiveness and how well they support the war fighters' needs. Nor does the fact that consolidated acquisition works in other countries mean it would work in the United States. As pointed out by McAleer (1989, p. 51), "our constitutional arrangement is fundamentally different from our European friends," as is the manner in which our programs are budgeted and funded. We cannot assume that what works in Europe or elsewhere will automatically work here. But this report would be remiss if it did not acknowledge such organizations exist, and that some were built from previously independent service acquisition organizations.

"The separation of powers [of our democratic government] creates a natural friction between Congress and the executive departments (in this case the DoD specifically)."

Political Influences

Politics is an inherent part of our democratic government. The separation of powers creates a natural friction between Congress and the executive departments (in this case the DoD specifically). Alexis de Tocqueville (Mayer, 1969) noted many years ago, "Democracy finds it's difficult to coordinate the details of a great undertaking and to fix on some plan and carry it through…." Congressional oversight of DoD (which some might call micromanagement), on everything from its budget and size to the location of its bases, has a major influence on the department's effectiveness and efficiency. Due to everything from congressional mistrust of the executive branch to congressional pork-seeking behavior, this oversight has increased steadily since the 1960s. However, we do not intend to defend, rationalize, or quantify the degree of oversight that is necessary or appropriate. Rather, we simply acknowledge that some degree of oversight is necessary to sustain our democratic form of government, and we'll leave the arguments over the degree of oversight to political scholars.

Historical Perspective

The premise that DoD's acquisition structure and organizations are ripe for consolidation is not new. In 1983 the President's Private Sector Survey on Cost Control's Task Force Report on the Office of the Secretary of Defense recommended consolidation of the "weapons acquisition process" under an Under Secretary of Defense for Acquisition; however, no action was taken on this recommendation. In 1986 the GAO looked at centralizing defense acquisition but recommended against such an action due to the estimated size of the resulting organization (GAO, 1986). A bill introduced to the 104th Congress in 1989 by Sen. William Roth of Delaware[4] proposed transferring "…all research, development, and acquisition functions of the secretaries of the military departments…[to] the Defense Research, Development, and Acquisition Agency." Reps. Barbara Boxer of California and Dennis Hertel of Michigan introduced

similar legislation. As happens with many such "radical" proposals, these bills died in committee.

The fervor to revamp defense acquisition seems to have gained momentum in recent years. Consolidating acquisition organizations was the subject of a CNA report in 1995 (DiTrapani, 1995). The issue was also raised during the 1997 Quadrennial Defense Review.[5] Congress voiced its desires through Section 912 of the 1998 Defense Authorization Act,[6] which directed the Secretary of Defense to "...conduct a review of the organizations and functions of the Department of Defense acquisition activities...." This review is to identify "...opportunities for cross-service, cross-functional arrangements; specific areas of overlap, duplication, and redundancy among the various acquisition organizations; alternative consolidation options for acquisition organizations; alternate acquisition infrastructure reduction options; [and] alternate organizational arrangements...." Furthermore, evidence shows that, in response to the 1998 Defense Authorization Act, the Defense Science Board will recommend consolidation of various research, development, test and evaluation, and acquisition organizations within DoD.

Why the increased pressure to overhaul DoD's acquisition organizations? Perhaps it's because so many previously independent factors have now converged. The big threats (communism and the Soviet Union) no longer exist. The national debt has reached an all-time high. Until just recently the federal budget deficit continued to rise. The public has called for reduced government spending—resulting in significantly reduced defense budgets. And some in DoD now contend that the only way DoD can afford to modernize its combat forces is to revamp its organization and business processes. As Dr. Gansler put it, only through an RBA can DoD's RMA be successful. Yet as we have seen in the past, as our research results clearly reinforce, attempts at major organizational change within DoD, such as establishing a single acquisition organization, face significant barriers from both within and outside DoD. As noted in the introduction, we will soon discuss those barriers and present ways to overcome them. However, before looking at the barriers, we should take a brief look at the process of introducing change in organizations.

"The fervor to revamp defense acquisition seems to have gained momentum in recent years."

Changing an Organization

Prior to collecting data on barriers to change within DoD, we reviewed literature on the change process and organizational and individual reactions to change. This literature review was conducted to gain a better appreciation of organizational change and to develop some insight into the reactions that should be expected from the research participants. The results of the literature review follow.

Change and Bureaucracies

The word "change" is contrary to bureaucratic functioning. Most bureaucratic organizations have been designed for stability. They were organized and managed with the belief that fundamental change

does not happen—that the future of the organization is basically the same as its past, and the goal of management is to maintain and perfect the model that was originally designed (Hammer, 1996, p. 209).

WHY CHANGE?

Change is pervasive in our society and a fact of life in organizations (Goodfellow, 1985, p. 25). The need for organizational change becomes apparent when a noticeable gap appears between what an organization is trying to do or should be doing, and what it is actually accomplishing. Change is especially necessary in organizations that wish to prosper in a volatile, uncertain, complex, and ambiguous environment (Steers, 1997, pp. 348-349). The question is no longer whether or not to change—today an organization has no choice but to change if it wants to survive.

From where does the impetus for change come? The simple answer is that it comes from the environment—an environment which is in a constant state of change and over which the organization and its leaders have little or no control. Strong environmental forces pressure all organizations to permanently alter the existing infrastructures, policies, and practices (Bolman, 1991). These forces are found both inside and outside organizations. Internal forces create unstable conditions within organizations and threaten efforts to achieve the organization's goals (Table 1). When stability and continuity are threatened, an organization must adapt its structure and processes in order to ensure its long-term growth and survival. External forces constantly change the environment in which organizations operate and compete (Table 1). These forces are increasing and organizations must respond and adapt if they hope to remain viable in the future (Steers, 1991, p. 616).

REACTION TO CHANGE

We all seek control in our lives and we fear and avoid ambiguity. Change causes ambiguity, and for this reason we fight against it. Change means people must let go of some of the habits, roles, processes, procedures and structures to which they've grown accustomed. Roles and relationships often become cloudy and unstable. Uncertainty and concern about the future emerge. People begin to feel incompetent and powerless—they lose self-confidence.

Table 1. Environmental Forces for Change[a]

Internal Forces	External Forces
Employee goal changes	Economic and market changes
Job technology changes	Technological changes
Organizational structure changes	Legal/political changes
Organizational climate changes	Resource availability changes
Organizational goal changes	

[a] Source: Steers (1991).

They experience difficulty severing their attachments to the symbols and symbolic activities they have developed over the years, leading to the loss of meaning and purpose. All of this results in anxiety, stress, conflict, resistance, and decreased organizational effectiveness (Steers, 1997, pp. 355–365).

Resistance is the force that opposes any significant shift in the status quo. It is a natural part of the change process and can be found throughout an organization. It's not the introduction of something new that people resist, it's the resulting loss of control. In fact, the phrase "resistance to change" is actually a misnomer. It's not the change people are resisting; it's the implications of the change—the ambiguity change brings with it (Conner, 1993, pp. 124–126). The reasons for resistance can be either personal or organizational. Table 2 shows some of the personal and organizational reasons for resisting change.

Change Agents

The manner in which leaders of an organization approach the change process ultimately determines the success of the change. In order for a change to succeed, leaders must become change agents—effective at influencing opinions and attitudes so as to persuade their followers to "release the familiar and embrace the unfamiliar" (Hammer, 1996, p. 220).

Study Methodology

Data Collection

The research questions formed the basis for collecting data for this study. The authors employed a focus group, questionnaires, and elite interviews to collect

Table 2. Reasons for Resisting Change[a]

Personal Reasons	Organizational Reasons
Misunderstanding of purposes, mechanics, or consequences of change	Reward system may reinforce status quo
Failure to see the need for change	Interdepartmental rivalry or conflict leading to unwillingness to cooperate
Fear of the unknown	Sunk costs in past decisions and actions
Fear of loss of status, security, power, etc.	Fear that change will upset the current balance of power between groups and departments
Lack of identification or involvement with change	Prevailing organizational climate
Habit	Past history of unsuccessful change
Vested interest in the status quo	Structural rigidity
Conflicting personal and organizational objectives	

[a] Source: Steers, 1991, p. 619.

responses to the research questions. The data from the focus group were used to validate the structure of the research questions, familiarize the authors with the type of answers to expect during interviews, and as input for the thematic analysis. The data from the questionnaires were used to help better structure the interviews and as input for the thematic analysis.

"The elite interview method was used because it allows the interviewers to define the situation as it really exists."

The elite interview method was used because it allows the interviewers to define the situation as it really exists (Dexter, 1970, p. 19). We adapted comments and questions to the unfolding interaction with the respondent during the interview. The interview approach focused on:

- stressing the respondent's definition of the situation;
- encouraging the respondent to structure the account of the situation; and
- letting the respondent introduce his or her own notion of what is relevant instead of relying on the investigator.

A copy of the interview questions was transmitted to the respondents in advance as an interview organizer. We authors served as the interview team. While we both asked questions and engaged in the interview process, one of us served as the primary interviewer while the other served as the data recorder. A tape recorder was not used. We compared notes after the interview and then recorded the results by question. In cases where more than one person participated in the interview, results were recorded as if only one respondent was involved.

Analysis

The data from the focus group, the questionnaires, and interviews were analyzed using content analysis to identify themes and relationships. Similar statements were grouped and those groupings were given a title that represented the theme.

Study Participants

The focus group consisted of seven faculty members from the Defense Systems Management College (DSMC), Fort Belvoir, VA.

The Executive Committee and Plenary Group memberships of the Defense Systems Affordability Council (DSAC) served as the basis for the target population for the questionnaires and interviews. The DSAC Executive Committee is chaired by the USD(A&T). Members of the Executive Committee include senior acquisition and logistics executives from the Office of the Secretary of Defense, Joint Staff, and the Services. The Principal Deputy Under Secretary of Defense (Acquisition and Technology) chairs the DSAC Plenary Group. Members of the Plenary Group include representatives of each Executive Committee member, other members from the Office of the Secretary of Defense, Overarching Integrated Product Team (OIPT) leaders, defense agencies, and the Services.

Selected program executive officers (PEOs), systems command (SYSCOM) commanders, and Congressional staffers were also included as part of the target

population for this study. Other acquisition leaders (e.g., PEOs and SYSCOM commanders) were not included due to their geographic location (outside the Washington, DC area), and the amount of time and resources the authors had to conduct the study.

The membership of the selected groups represent the acquisition stakeholders within DoD and serve as the most appropriate people to collect responses to the research questions.

Results

Thirteen questionnaires (42 percent) were returned from the 31 distributed to the target population. Ten interviews (43 percent) were conducted from the 23 requested of the target population. The overall response rate was 42 percent. The following were identified by the study participants as major barriers to a single DoD acquisition organization:

Service Cultures

This cultural barrier is based upon behavior theory. The data saw this as a tremendous challenge since much of the "old timers'" behavior was too ingrained due to years of association with service tradition and values. Lasting change would have to be based on an intrinsic desire to do so. Many did not see this happening; therefore, it is necessary to start inculcating a "new way" within the services.

Our review of literature on the change process discovered that an institutionalized culture often considers change almost unthinkable (Wilkins & Dyer, 1988). Employees, including many managers, who either don't identify with or don't understand the planned changes, will passively resist change by dragging their feet. It should be noted however, that many personal reasons for resisting change are not intended to prevent attaining the goals of the change. Instead, resistance often results from fear of the consequences of the change and a preference for the known over the unknown (Steers, 1991, pp. 618–619). Thus the DoD reaction is typical of an organization facing change.

Parochialism

Parochialism among the services is rooted deep in tradition and cultural values that are more than 200 years old. Change within such an embedded culture is a tremendous challenge. Data suggests that the current structure of the services within the DoD organization prevent such a change from occurring.

Literature on the change process indicates that the nature and character of an organization affects the way in which change is accepted. For example, when departments see each other as rivals they may undermine cooperative efforts at change in order to protect their turf. Also, leaders often choose to live with past decisions rather than admit conditions have changed (Steers, 1991, pp. 618–619). Therefore, the reaction of the services, that each is different and must remain totally independent, is typical of an organization facing change.

Title 10 *United States Code*

Title 10 *United States Code* states that each Secretary of a military department has responsibility for equipping the forces (to include research and development).

Feedback from the interviews and questionnaires indicated that some view this as a legal barrier preventing the consolidation of the service acquisition organizations into a single DoD acquisition organization.

The literature on change noted that members of an organization with precise regulations that control the way in which the organization operates will be reluctant to accept change (Wilkins, 1988). The desire to continue following the known and accepted rules without challenge avoids ambiguity and uncertainty. Again this DoD reaction to proposed change is typical.

"Our research uncovered a strong feeling among the services that the generation of, and proponency for, requirements must remain with them."

Retaining the Link Between Services and Requirements

Our research uncovered a strong feeling among the services that the generation of, and proponency for, requirements must remain with them. They also felt that movement of their acquisition organizations under a consolidated organization would create a barrier between the "buyers" and the "maintainers." There was nothing in the literature on change addressing this type of barrier or resistance to change. Thus it is assumed that this reaction is unique to the DoD.

Service-unique Roles and Missions

There is a tendency among the services to want to do their "own thing." There is a difference in the way they fight; in the environments they encounter; and in the equipment they desire. There is a general feeling that these unique roles and missions require unique systems that meet unique requirements. Furthermore, only individuals directly associated with the individual services themselves can adequately fulfill these unique needs. A centralized acquisition organization is considered unable to meet the unique service needs.

This barrier is another example of what the literature on change characterizes as the nature and character of an organization affecting the way in which change is accepted. It exemplifies a situation in which departments see each other as rivals and undermine cooperative efforts at change in order to protect their turf (Steers, 1991, pp. 618–619). This reaction by the services is typical of an organization facing change.

Leadership: No Real Change Agent

Under the current scenario, the data suggest that DoD is unwilling to make the necessary changes itself due in part to:

- no real change agent;
- no imperative (threat) for change;
- insufficient time for a single administration to get incremental changes accomplished; and
- no vision setting (e.g., using 18th-century thinking to fight an asymmetrical threat).

For example, the acquisition workforce has been reduced by 50 percent, yet most

of DoD continues doing acquisition business the same way it was done before the reduction. The DoD has not examined and re-engineered the acquisition and business processes.

Much has been written in the literature on change concerning the need for strong, visible leadership (Steers, 1997). There are examples of many organizations that attempted to undergo change without change agents—most of which resulted in failure. Also, if previous attempts by the organization to change were poorly planned and unsuccessful, employees will assume new attempts to changes will also fail (Steers, 1991, pp. 618–619). This barrier is by no means unique to DoD.

No Centralized Requirements Organization

This barrier is characterized by the services not being able to control the requirements process to meet their individual desires. As a result, the requirements may be suboptimized for what is "best" for an individual service. Furthermore, with each of the services determining "their" requirements, there is no organization that can prioritize the overall requirements for the proposed single acquisition organization. This situation is exacerbated by the fact that the Joint Requirements Oversight Council (JROC) process only looks at acquisition category (ACAT) I programs.

There was nothing in the literature on change addressing this type of barrier or resistance to change. Thus it is assumed that this reaction is unique to the DoD.

Conclusions and Recommendations

DoD's reaction to change is typical of any bureaucratic organization. The organization was designed for stability and thus resists fundamental change. Many managers have become engrained with the culture of the organization—they believe the future of the organization is in keeping with its past and that their goal is to maintain and perfect the original model (Hammer, 1996, p. 209).

While it was not our intent to take a stand on consolidating defense acquisition organizations, it is hard to ignore the inadequacies in the current acquisition system. The data collected during our research did point to the need for changes in DoD's acquisition system and organizations. If the DoD is serious about remaining viable in this environment of diminishing resources, it must change its business practices in a manner similar to that which industry made. These changes, many of which will be unpopular, must include streamlining organizational structures; re-engineering processes; eliminating duplication; and modifying cultures. In order for these changes to take place DoD must have a strong "change agent" willing to take calculated bold moves without overriding concern for political impacts, willing to work to overcome the resistance of an entrenched workforce. The paragraphs that follow provide recommendations from our research that can help overcome the major barriers to consolidation and, in

"DoD's reaction to change is typical of a bureaucratic organization."

the absence of a total consolidation, can help implement the changes needed in today's acquisition system.

Service Cultures

Leaders should be supported and promoted if they model and nourish the "new" behavior of jointness required to overcome these barriers. True jointness, although expressed verbally, is not really practiced. For change to be lasting, it must be fostered by strong leadership and driven from within the individual and not forced extrinsically. While not all tradition is bad, some traditions (e.g., single-service bases, individual academies) would be counter to new joint doctrine and should be removed.

Parochialism

It was postulated that a "Goldwater-Nichols II" was needed. The thrust of such a change would:

- eliminate service secretaries and service department staffs;
- direct service chiefs to report to the Chairman, Joint Chiefs of Staff (CJCS);
- revise and expand joint doctrine under the direction of the CJCS;
- educate and train a joint force that would include joint service academies, joint Reserve Officer Training Corps programs, basic and advanced courses, and capstone courses;
- create joint assignments at the operational level;
- create joint bases; and
- provide joint maneuver exercises (including modeling and simulations).

At the Keynote Address given to the February 1998 American Institute of Aeronautics and Astronautics, Inc (AIAA) Conference on Acquisition Reform, retired ADM William Owens suggested that practically everything done within the DoD should be done in a "joint mode." As an example he suggested that a joint service academy operation would have an individual attend the Naval Academy the first year; followed by West Point for the second year; the Air Force Academy for the third year; and back to the Naval Academy for the final year.

Removal of service secretaries and service staffs (with the service chiefs reporting to the CJCS) might be perceived as a dilution of civilian oversight. However, direct civilian oversight would just be shifted to the Secretary of Defense level. Such a suggestion may best be received from the community if it were supported by previous CJCSs, as well as current and former service secretaries.

Title 10 *United States Code*

The data in a related study (Fox, 1994, p. 7) suggests different legal ways of implementing Title 10 statutes in addition to how it is currently being implemented. According to the Fox study, even with a consolidated acquisition organization, the intent of Title 10 would be met if "...the Service secretaries retain responsibility for initiating the acquisition program process to equip the forces, formulating acquisition budgets, and making priority

decisions among acquisition programs competing for scarce resources. The services can also retain responsibility for operational test and evaluation; they would become "customers" who submit orders for equipment to an acquisition organization charged with obtaining this equipment with agreed-to cost, schedule, and technical performance parameters. Indeed, this type of practice occurs today: the Army is the single manager for acquisition of conventional ammunition within DoD, while the other services continue to establish their ammunition requirements and budgets." However it was suggested by our research that it would take a significant paradigm shift or "metanoia" (Senge, 1990. pp. 13–14) among many DoD players to overcome this perceived barrier.

Maintaining the Link Between Services and Requirements

It was suggested that the true proponent for war fighting requirements should be the commanders-in-chief (CINCs) and not the services themselves. Under this scenario war fighting requirements would not be linked to the services but rather to the CINCs. The services would be responsible for ensuring the CINC's requirements were fulfilled. Making the CINC's members of the JROC would be the first step toward this change.

Service-unique Roles and Missions

The changes recommended above for service cultures and parochialism were also recommended for overcoming this barrier.

Leadership: No Real Change Agent

Resistance to change is a natural phenomenon within organizations. To achieve change via a "metanoia," DoD and the services must have a strong change agent willing to take a stand on needed dramatic changes (e.g., ADM William Owens and jointness, VADM Arthur Cebrowski and RMA/C3ISR, Gen William (Billy) Mitchell and the use of aircraft carriers, and ADM Hyman Rickover and the use of nuclear power and submarines).

No Centralized Requirements Organization

As a solution to this barrier, the data suggests that the CJCS should direct CINC membership on the JROC at the appropriate (deputy CINC) level and expand the scope and capability of the JROC by reviewing all ACAT levels. This approach would make for a "true joint process" and would:

- reduce duplication of effort among services;
- give war fighters direct input into the acquisition process;
- be a step toward developing and creating a single DoD acquisition organization; and
- improve "jointness" through the joint development of doctrine, equipment, and forces.

Eliminate Duplication

Recognizing that consolidation of all DoD acquisition organizations may be an

impossible task, perhaps taking smaller steps to eliminate duplication is a more palatable idea. For example, C4ISR should be common or at least compatible across the DoD. Thus consolidation of the organizations acquiring these systems should be considered as a test case for further consolidation within the DoD. Additionally, consolidation of laboratories, software development organizations, organizations acquiring aviation systems, and organizations acquiring ground-related systems should also be considered.

J. Robert Ainsley is currently assigned to the Office of the Commandant as the program manager for the Acquisition Management Curriculum Enhancement Program (AMCEP), where he is responsible for the continual design and development of the program management curriculum continuum that supports the developmental needs of the acquisition workforce. Dr. Ainsley also serves as the chair of the Acquisition Management Functional Board/Defense Systems Management College (AMFB/DSMC) Joint Special Working Group (JSWG) for the enhancement of the Advanced Program Management Course (APMC). Prior to this assignment, Dr. Ainsley served as the director for the Executive Program Manager's Course, where he had lead responsibility for the design, development, and implementation of the course.

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ENDNOTES

1. Information provided by an OSD staff member during an interview with the authors during March 1998.

2. See Center for Naval Analysis Report (1995, April, CMR 95-64) for detailed information on the pro's and con's of consolidating DoD's acquisition organizations.

3. For additional information on this topic see Houston, C. (1997); Krikorian, G. K. (1992); or GAO (1986, February, Report NSIAD-86-51FS).

4. S. Res. 646.IS, 104th Cong., 1st Sess. (March 29, 1995).

5. 1997 Quadrennial Defense Review.

6. 1998 Defense Authorization Act.

QUANTIFY RISK TO MANAGE COST AND SCHEDULE

Fred Raymond

Too many projects suffer from unachievable budget and schedule goals, caused by unrealistic estimates and the failure to quantify and communicate the uncertainty of these estimates to managers and sponsoring executives. Some projects are beginning to use Monte Carlo methods to improve cost and schedule estimating; however, it is not always done in a systematic manner, mutually understood by both customer and supplier. This article provides a systematic approach based on quantification of expert judgment in a pragmatic and consistent fashion.

Projects often fail to predict or accommodate the risk and uncertainty of budgets and schedules in a rigorous or structured manner. This is of particular consequence in the "better, faster, cheaper" era of program management. The risk is seldom quantified in a manner that the estimators, the management hierarchy, and the customer mutually understand, accept, and acknowledge. Furthermore, projects are often planned to "best-case" even though few of the participants, particularly the managers and sponsoring executives, recognize and understand the implications of a best-case, "green-light" plan. Although it may indeed be prudent to work to such a best-case plan, managers and executives fail to concede that the probability of achieving the "best-case" goal is by its very nature *zero*[1]—and that faster and cheaper is also riskier. This failure inevitably results in misunderstandings and unrealistic goals.

Some projects, as a result of such unrealistic goals and with pressure from an uninformed customer, are driven to establish harsh policies that serve to undermine the very objectives they hope to achieve. Methodical and rigorous quantification of the uncertainty of cost and schedule estimates is key to interpreting, and realistically managing and mitigating, cost and schedule risk. This, in the end, will lead to improvement of overall project management.

Expert Judgment

Expert judgment is typically the crux of cost and schedule estimates, but in the spectrum of the risk management process, quantification of expert judgment is the weakest area. Transitioning from English language statements of experts to the mathematical expressions required by analytical tools is done inconsistently if done at all. Professional program planners are beginning to apply statistical methods to schedule and cost analysis in an attempt to deal with this problem.

"Expert judgment is typically the crux of cost and schedule estimates, but in the spectrum of the risk management process, quantification of expert judgment is the weakest area."

This article offers a methodology for statistically quantifying the risk to cost and schedule resulting from the uncertainty[2] of the estimates that underlie any cost-schedule analysis. Some simple rules for cost-schedule risk mitigation are postulated that provide a structured focus for the methodology offered. These rules provide the expert with a logic basis that is fundamental to consistent and sensible quantification of the risk elements. These rules are:

- Plan "best case" and preclude implementing a self-fulfilling prophesy.
- Budget "most likely" and recognize real-world risk and uncertainty.
- Protect for "worst case" and acknowledge the conceivable.

Crucial to implementation of these rules is the credibility of the best-case estimates. They must be honest and truly achievable in the best-case scenario; unrealistic targets cannot drive them. Only then can a credible quantification of risk be applied. On this basis, a specific approach to interpreting expert judgment and quantifying cost and schedule risk is offered.

Statistical Analysis

The term "risk" implies a stochastic (probabilistic) process, and quantification requires a model. Such a model can be developed by ascribing to each element of the cost estimate, or the schedule projection, a probability distribution function (PDF) representing the likelihood of completing the particular cost element or scheduled task at a specific cost or for a specific duration. Monte Carlo simulation techniques can then be applied to the model to forecast the entire range of possible end results.

A simple triangular distribution is a reasonable PDF for describing the risk or uncertainty for a cost element or task duration estimate. Its structure is based on the minimum possible cost and duration (plan best case), the most likely cost and duration (budget most likely) and the maximum possible cost and duration (protect for worst case) as illustrated in Figure 1.

The height of the triangle is 2/(max-min) such that its area is unity. The parameters are simple, intuitively easy to comprehend, and amenable to a mathematical formulation compatible with cost and schedule models and fast Monte Carlo analysis. Other more complex distributions

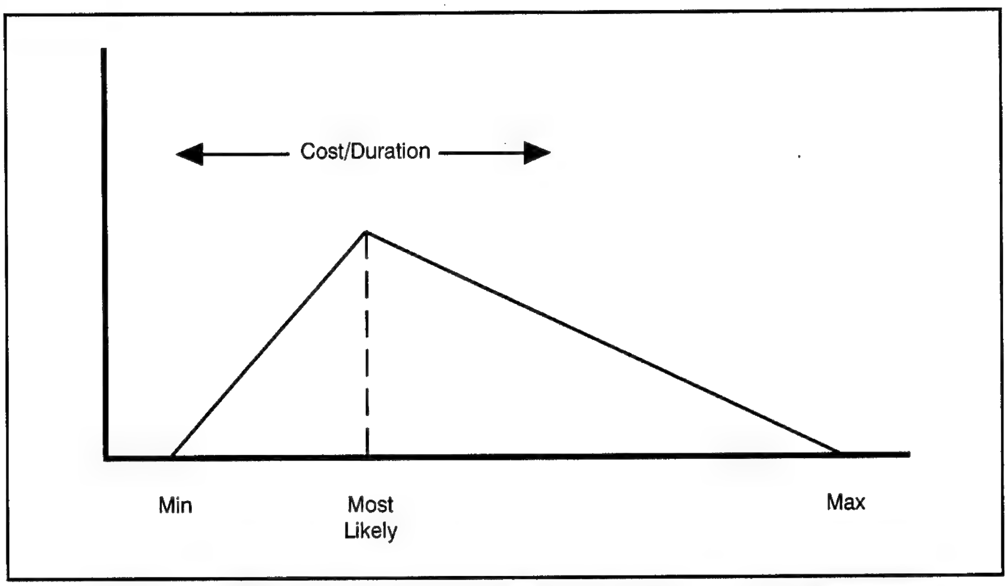

Figure 1. Risk Uncertainty for Cost Element or Task Duration

could be used such as the Beta or Weibull, but little if anything is gained,[3] and the intuitive simplicity of the triangular distribution is lost. The triangular PDF will form the basis of the quantification of risk offered here.

Table 1. Risk Factor Multipliers

Code		Min	Most Likely	Max
Low	L	1	1.04	1.10
Low+	L+	1	1.06	1.15
Moderate	M	1	1.09	1.24
Moderate+	M+	1	1.14	1.36
High	H	1	1.20	1.55
High+	H+	1	1.30	1.85
Very high	V	1	1.46	2.30
Very high+	V+	1	1.68	3.00

QUANTIFYING JUDGMENT

The "expert" is first asked to provide a green-light, best-case estimate of each cost or schedule element in the model, and then is asked to provide an assessment of risk (his or her unsureness) associated with the estimate for each element. Table 1 relates the risk adjectives of low, moderate, high, and very high to a set of risk factor multipliers.

The table has been developed to facilitate and guide the expert in risk estimation. These factors, when multiplied by the best-case estimate, are the parameters of the triangular PDF for a particular element of cost or schedule based on its associated risk.

This table is intended to provide a reasonable range of risk quantification that fits well with the perceptions and experience of engineers and estimators. It is based on the author's experience as a project manager, planner, proposal evaluator, and as an expert providing cost and schedule estimates for many years and on many projects. The table has also been used by engineers at the Naval Research Laboratory to develop cost and schedule estimates for spacecraft projects. The engineers adapted readily to the table and were content with the adjectives and the range of the associated multipliers. The author is unaware of any other reference that would serve to substantiate (or refute) Table 1. It is suggested that an approved standard for these multipliers be developed that is generally accepted and consistently applied industry-wide. Table 1 can be used in the interim and can serve as a point of departure for a more widely accepted standard.

"[This table] is based on the author's experience as a project manager, planner, proposal evaluator, and as an expert providing cost and schedule estimates for many years and on many projects."

These particular risk factor multipliers are arithmetically derived from a few basic assumptions, which provide a structure and logic to the risk-factor multipliers that may facilitate the debate and development of a standard. They are as follows:

- For an element of a cost or schedule estimate coded low risk, "max" (worst-case performance) is defined as 10% greater than "min" (best-case performance) and "most likely" is defined as 4% greater than "min." This reasonable premise for a low-risk element provides a base for the derivation.

- The "most likely" set is then derived as a geometric progression of the percent increase for the eight risk codes with a common ratio of 1.5 (e.g., 6% = 1.5 x 4%, 9% = 1.5 x 6%, and so forth as the risk increases from low to very high).

- For an element coded as "very high+," "max" is capped at 200% greater than "min." The rationale for this cap is that no prudent manager would allow a growth beyond three times plan without intervention and mitigating action.

- The common ratio (1.534) for the "max" geometric progression is then derived from the first and last element of the set (e.g. 10% and 200%).

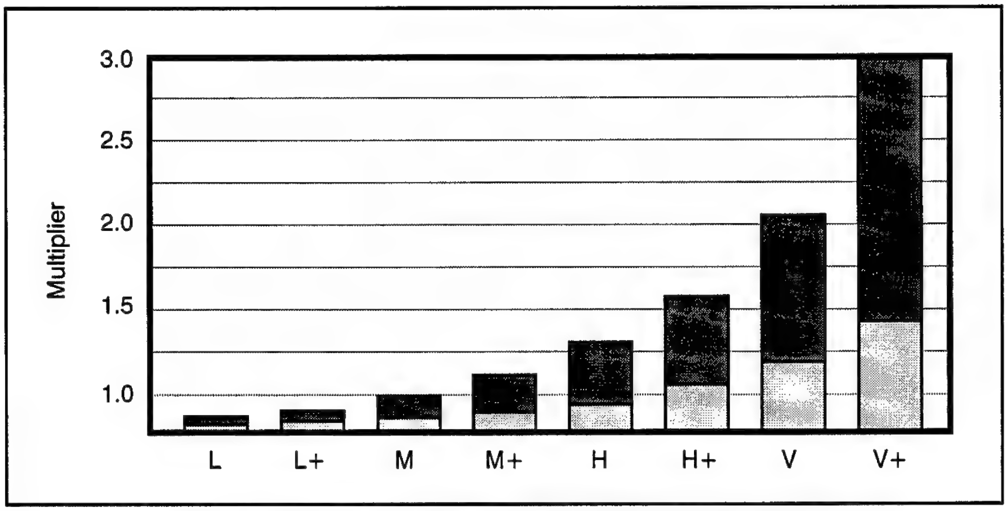

Figure 2. Risk Factors Graphically Illustrated

The multiplier factors associated with the hierarchy of risk approximate a geometric progression. Therefore, as the risk increases, the probability distribution becomes more asymmetrical on the "max" side, as we intuitively would expect. An additional degree of flexibility is provided by the inclusion of the "+" categories.

These factors, illustrated graphically in Figure 2, provide a convenience to the estimator; their use will provide a degree of consistency from estimator to estimator and from estimate to estimate.

Risk Factor Attributes

Below, typical attributes are suggested that characterize the risk factors. These attributes illustrate situations that could be a basis and substantiation for a particular risk evaluation. Risk factor attributes can be tailored for a particular project and perhaps they could be expanded as part of establishing an approved standard; however, care should be taken not to develop rigorous cookbook bureaucratic tests. We must accept that in the end all estimates are judgments, hopefully made by experienced individuals who are motivated and unfettered in their task. Most expert evaluators will rely on their own experience as guided by Table 1.

Low-Risk Attributes

As applied to design tasks. Existing proven designs are used extensively; requirements are well defined and readily achieved; development effort is minimal; and an innovative approach materially simplifies design implementation.

As applied to production. Extensive use is made of proven hardware or software produced by previous suppliers; exotic processes and tooling are not required for production; materials and parts are readily available; and an innovative approach materially simplifies production.

As applied to test and verification. Extensive use is made of proven hardware

and software produced by previous suppliers; alignments and calibrations are not critical; test tools and equipment are readily available; and an innovative approach materially simplifies testing; performance demands are reasonable and have been realistically suballocated; design provides significant margin above the requirement; achievement of the design margin is not precipitously crucial to mission success; and an innovative approach materially simplifies accomplishment of the mission requirement.

Very High Risk Attributes

As applied to design. Extensive use is made of new and unproven designs; requirements are poorly defined and unlikely to be achieved; development effort is extensive; and an "innovative" approach materially complicates the design.

As applied to production. Extensive use is made of unproved hardware or software never previously produced; many exotic processes and undeveloped exotic tooling are essential for successful production; materials and parts are not in production, require development, are in short supply, or otherwise are not currently available through normal vendor procurement; an "innovative" approach materially complicates production.

"A grade of 'moderate' or 'high' is based on the evaluator's judgment, considering the risk extremes as defined for 'low-risk' and 'very high risk.'"

As applied to test and verification. Extensive use is made of unproved hardware or software never previously produced; most alignments and calibrations are difficult and critical to performance; exotic test tools and equipment are essential, not readily available, and require development; designs result in unstable platforms, timing interfaces, and electrical outputs; an "innovative" approach materially complicates testing; the allocated performance budget is unrealistic; the design provides no significant margin above the requirement; achievement of the design margin is precipitously crucial to mission success; and an innovative approach materially complicates accomplishment of the mission requirement.

Moderate and High-Risk Attributes

A grade of "moderate" or "high" is based on the evaluator's judgment, considering the risk extremes as defined for "low-risk" and "very high risk." Attributes will range from modification of existing design or catalog design to new designs and high technology.

Interpreting the Results

The composite results of a Monte Carlo analysis of a series of cost elements in a hypothetical project will be a probability forecast such as that illustrated in Figure 3. In concert with the risk mitigation rules cited at the beginning of this article, the project manager would initially allocate a budget to his project elements totaling about $110 million, while retaining about $8 million as his total operating management reserve.

Furthermore, he would alert his customer to the possibility that if all goes bad, the project could cost as much as $128 million. The customer may elect to take action to protect his funding allocation for this worst case. The analysis will reveal

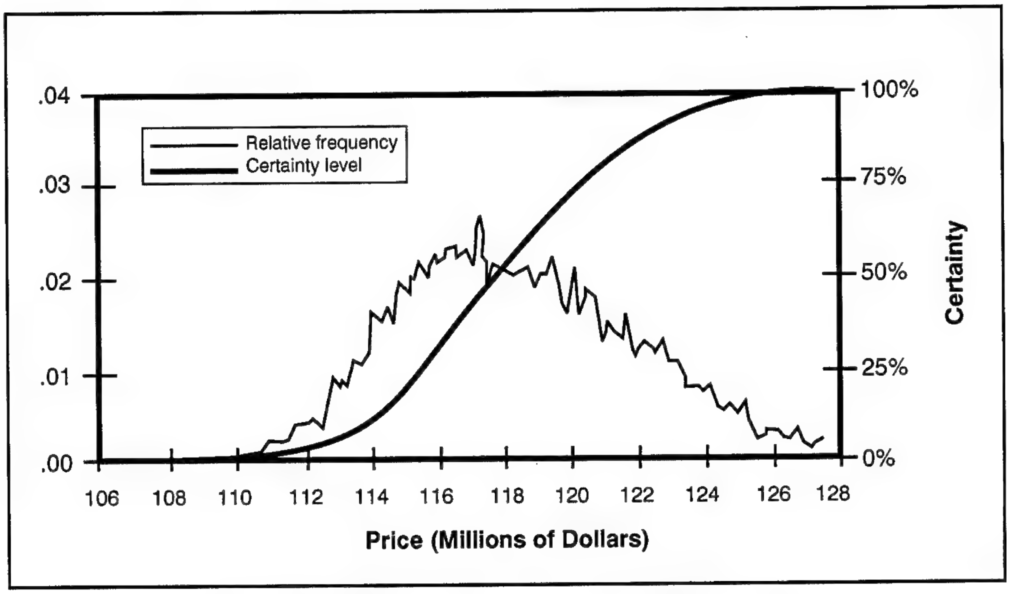

Figure 3. A Monte Carlo Price Forecast

the high-risk cost elements so that they can receive the special management attention warranted.

The corresponding Monte Carlo probability forecast of a series of interdependent schedule elements for our hypothetical project might be similar to that in Figure 4. The schedule risk is quantified and illustrated for all to see and better understand the uncertainties of the

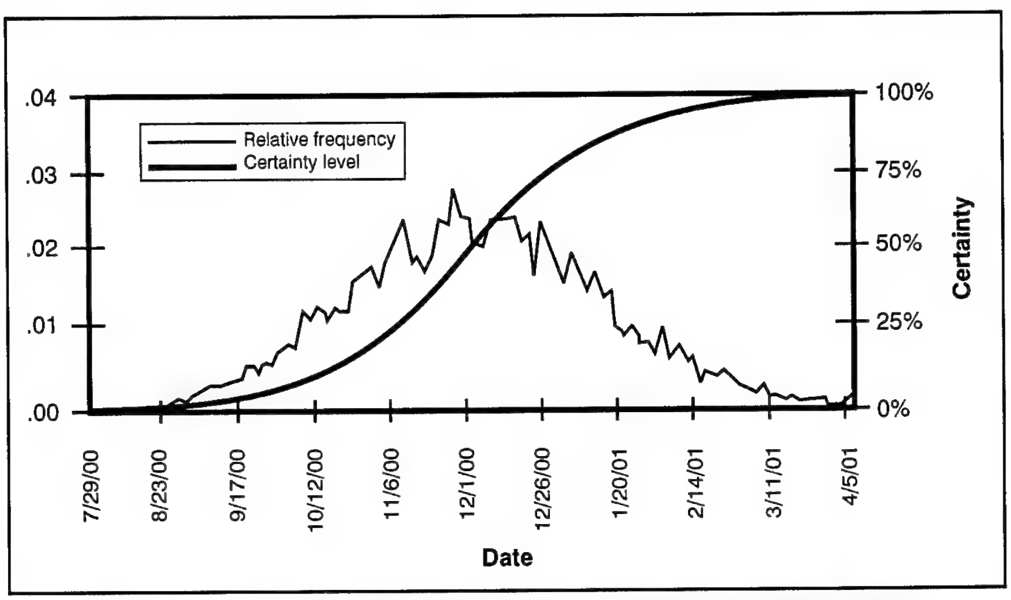

Figure 4. A Monte Carlo Schedule Forecast Completion Date

project. Based on this analysis the project manager would take action necessary to accommodate both the possibilities of an early delivery or a late delivery. The Monte Carlo schedule risk analysis may well reveal that the critical path does not determine the most likely delivery date as commonly assumed. A noncritical path that has much higher risk may drive delivery. Quantification and identification of these high-risk paths will direct and help focus management attention to the truly critical program elements.[4]

CONCLUSION

Cost and schedule risk mitigation can best be done if the risk is quantified. Building detailed cost and schedule models are always formidable tasks, and adding the complexity of risk estimates can be a significant extra effort. But with the simplified, pragmatic approach suggested here, such quantification of risk is a practical and productive effort. The computational tools and the software to support the methodology suggested are currently available. The benefit of quantified risk is best illustrated by the wealth of management information clearly communicated by the previous two summary forecast charts. Forecasts, made for projects at the Naval Research Laboratory, such as the interim control module (ICM) for the NASA space station, have provided a management recognition and comprehension of the impact of uncertainty and risk associated with schedule and cost projections. All managers will be well served by using such data.

Frederick W. Raymond retired from government service and the Navy Space Program in 1986. At the time of his retirement he was serving as spacecraft acquisition manager for the Navy Space Special Projects Office. Previously, he was extensively involved in the design development and production of Navy satellite systems as deputy head of the Spacecraft Technology Center of the Naval Research Laboratory. He has more than 30 years' experience in space technology and procurement management. He was a founder and vice president of Welkin Associates, Chantilly, VA. In August 1997 he returned to the Naval Research Laboratory and is now a senior advisor at the Naval Center for Space Technology. He holds a B.A. degree and an M.S. degree in physics from Syracuse University.

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ENDNOTES

1. Cost and schedule estimates are made up of many independent elements. If each element is planned as best case—say with a probability of achievement of 10%—then the probability of achieving best case for a two-element estimate is 1%; for three elements, .01%; and for many elements, infinitesimal. In effect, it is zero.

2. No attempt will be made in this article to distinguish between risk and uncertainty. Risk involves uncertainty but it is indeed more. For purposes of this article it is unimportant. The effect is combined into one statistical factor we call "risk," which will be described by a single probability distribution function.

3. The difference that may result from a Monte Carlo forecast of a triangular PDF and a forecast using a corresponding Beta or Weibull PDF is most certainly masked by the accuracy of their estimated parameters.

4. This article addresses the forecast of possible outcomes of cost and schedule and not the system or program impact. With these forecasts managers can anticipate and plan for possible impacts.

GENERAL FLIGHT TEST THEORY APPLIED TO AIRCRAFT MODIFICATIONS

Lt Col Lionel D. Alford, Jr., USAF and Robert C. Knarr

Any external aircraft modification has potentially far-reaching effects on the capability of the aircraft to succeed or fail in its mission. The authors take a systematic look at the effects that small changes can have upon the whole, with a series of examples that demonstrate why careful review of data or testing is often vital in the assessment of system modifications.

A new design aircraft program always includes an instrumented test to validate the analyses. But a modification program may rely instead on previously collected data for model validation. Such a program must adequately address the effects of the modification on the aircraft and its mission. The user must judge these effects for their desirability—especially when they degrade mission capability. But, to be judged, they must be fully understood. Reviewing historical data or conducting a test are two ways to validate the data by which these effects on aircraft capability are judged.

In this article, we address eight critical test and evaluation considerations for an external aircraft modification. The aircraft design problems covered here represent the fundamental characteristics by which aircraft capability is judged. These design problems, when not properly analyzed and tested (if required), have historically resulted in significant degradation of air worthiness. We define the subject area and explain the importance of each problem by discussing the rationale behind standard design practices and air worthiness and operational considerations for the fleet aircraft. Concrete examples illustrate each case. Although only effects to the C–130 aircraft are discussed in detail, these principles and observations apply to any aircraft.

Structural (Stress and Loads Analyses)

Rationale. When structural strength proof tests are not performed, it is a standard engineering practice to specify that aircraft modifications be designed for a 25 percent or greater static margin of safety using a factor of safety of 1.5. The modified airframe will then have the strength capability to be released to fly at 100 percent of design capability. However, if analyses show that an aircraft has a margin of safety between 0 and 25 percent, then the aircraft must be tested with sufficient instrumentation to ensure a positive margin of safety for the ultimate design conditions in order to prevent flight envelope restrictions. Finally, if analyses reveal a negative margin of safety or failure occurs during testing, either the deficient structure must be redesigned or aircraft flight envelope restrictions must be imposed.

"In fact, the most prolific sponsor of research competitions is the federal government, and in particular the Department of Defense."

Air worthiness and operational considerations. Reduction of the flight envelope means the aircraft must be restricted in airspeed, symmetric or maneuver G-loading, sideslip, or payload to prevent a design load limit (DLL) from being exceeded. Limiting the C–130 flight envelope as a result of any modification will significantly affect the aircraft mission capability. This is to be avoided at all cost.

The ultimate result when an aircraft is not designed to standard engineering practice (or verified by test) is increased likelihood of component or structural failure. An example of this is skin surface antenna mounts that come off in flight due to repeated flights at high airspeeds. Structural modifications that pierce the pressure vessel and are grounded in the load-bearing components of the aircraft are a special threat. This is because those components, when they fail, have a tendency to cause the failure of other load-bearing structures. This domino (a.k.a. zipper) effect can result in the loss of an aircraft. The loss of a modified KC–135 aircraft in the early 1970s was probably attributable to such a failure in a fuselage-mounted radome. Another problem symmetric modification can create is asymmetric loading. As a result of even the most benign maneuvers, the modification may be subject to airloads that cause oscillations in the fuselage. This can result in fatigue failure of structures well forward of the modification. The Beech V-tailed Bonanza is a classic example of this; the shape of the tail caused fishtailing that eventually resulted in fuselage failure.

Pressurization

Rationale. Pressurization is directly related to the previous discussion. It is in its own category because it is a common and potentially catastrophic failure mode in modifications. Generally, when the aircraft pressure vessel is penetrated, for whatever reason, a full pressure test series (proof and leakage rate) is made on the aircraft. Following a significant modification, a full pressure test must be completed prior to

the first flight during which the aircraft will be pressurized. The pressurized portion of the aircraft must be capable of withstanding proof-pressure testing at a level 1.33 times the maximum setting plus tolerance on the safety valve. This test should be performed on each modified aircraft.

Air worthiness and operational considerations. The importance of verifying pressure vessel integrity is evident from the standpoint of the potential consequences of a modification failure which breaches the pressure vessel. Pressure vessel failures have the potential to cause the loss of an aircraft due to an explosive decompression. An example of this is the C–130 flying near Iceland that had a breach near the wing root; it lost most of the top of the center wing and some of the fuselage. This aircraft made it back safely; many crews have not been so lucky. With any depressurization there are additional safety hazards to the crew as well.

FLUTTER, BUFFETING, AND VIBRATION

Rationale. Airframe vibration comprises three distinct areas: flutter and aeroelastic instabilities, dynamic loads, and vibroacoustics. Flutter deals with dynamically unstable elastic coupling of the airframe with the air stream, and occurs primarily in the lowest frequency airframe elastic modes. Dynamic loads deal with the forced vibration resulting from buffeting, atmospheric turbulence (gust), landing impact, sharp maneuvers, heavy store release, and other factors, again in the lowest frequency airframe elastic modes. Vibroacoustics deals with the forced vibrations of the airframe in the higher frequency local modes as driven by jet noise, aerodynamic turbulence, unbalance in rotating equipment, propeller or rotor blade aerodynamic disturbances, gun blast, etc. They can also cause control problems (which will be discussed in the section on handling qualities).

Flutter is the dynamic instability of an elastic body in an airstream. Flutter speed (Uf) and the corresponding frequency (vf) are defined as the lowest airspeed and frequency at which a flying structure will exhibit sustained, simple harmonic oscillations. Flutter is a dynamic instability (self-sustaining and increasing) that may result in failure of the structure. In aircraft, the failure of a main structure generally results in the loss of the aircraft. Aircraft are designed such that their airframe flutter will occur at airspeeds and conditions outside the aircraft envelope by a safety margin of at least 15 percent. Modifications that change the vibrational modes of an aircraft cause the flutter speed to change.

"Flutter is the dynamic instability of an elastic body in an airstream."

The frequency and airspeed at which flutter occurs generally increases with increased structural stiffness. However, many times increased stiffness in a structural component changes the vibrational frequencies of that component and result in changes of frequencies in the overall aircraft structures. These changes can cause unforeseen consequences such as vibration or flutter, and their effect must be evaluated by analyses or testing. Usually, a ground vibration test is made to determine changes in the vibrational modes of a modified airframe. These

modes are used to validate or update the structural dynamic analysis model that determines the flutter speeds and frequencies.

Buffet is the elastic structural response of the airframe in the lower frequency structural modes to aerodynamic flow separation or shed vortices. Flight surfaces (wings, tail surfaces, etc.) buffet due to the oscillating forces as flow separates and reattaches over local areas. Buffet also occurs when surfaces downstream of flow separations are elasticity excited by the flow turbulence or by shed vortices. If buffeting occurs or if it is considered likely (there is no analytical procedure to predict these phenomena), the surface must be instrumented and flight tested. If testing shows surface loading outside the design load limits, the modification must be redesigned or the aircraft restricted.

"[Vibration] can result in fatigue failure of structures, particularly lightweight structures directly in the slipstream, such as wing flaps."

Vibration is the elastic response of the higher frequency modes of the airframe to the boundary layer turbulence, jet noise, and other high-frequency load and pressure oscillations. The primary source of vibration excitation in propeller aircraft is the pressure field that rotates with and flows aft of the propeller. It can result in fatigue failure of structures, particularly lightweight structures directly in the slipstream, such as wing flaps. Vibroacoustic measurements are made in general locations around the airframe, in specific locations of known problems, or in locations where severe flow disturbances are suspected.

Air worthiness and operational considerations. Flutter is a special concern for the C–130 empennage and can be a problem for any wing- or empennage-mounted modification. The A model of the aircraft was analyzed with a 15 percent flutter safety margin, but exhibited approaching flutter during high-speed flight. The aircraft was limited in airspeed due to this problem. The B model was redesigned with greater rudder and elevator tip weights to change the frequency of the surface bending and fuselage torsion and get back to the 15 percent safety margin. Any modification that changes the fuselage torsion or fin-bending modes has a potential to cause flutter in the C–130 empennage. Because of this, special care should be taken to ensure that modifications do not negatively affect the aircraft's flutter safety margin. With the advent of high-speed digital computers and the accompanying analysis tools, the ability to examine this phenomena during the modification design phase has been greatly enhanced.

The C–130 wing modifications result from the long-term vibrational effects on the airframe. The wing structural components were so weakened by vibration and stress that a couple of aircraft were lost and the entire fleet had to be restricted until modifications could be made.

All airframes are subject to some degree of buffet, higher level boundary-layer turbulence behind flow obstructions, and shed vortices. These loads cause structural problems in particular circumstances where elastic airframe modal frequencies are coincident with the frequency content of the aerodynamic excitation. When high frequencies are involved (vibroacoustics), the failures are often

rapid. Blade antennae are particularly sensitive to this type of excitation, and if located in regions of disturbed flow, they often separate from the aircraft. Even when these effects are not dramatic, aeroacoustic fatigue caused by buffeting is a serious problem for modified aircraft. This is demonstrated by structural cracking (a hole) on the fuselage of a C–135 (No. 4128, <30 flight hours after modification) caused by the separated flow behind a radome.

Handling Qualities

Handling qualities include static stability, tail plane control margins, mass properties, and dynamic stability.

Rationale. Handling qualities comprise many of the specific qualitative and quantitative areas involved in flight. Any modification to the exterior of an aircraft may affect the static or dynamic stability and control of an aircraft as a function of the modification's lift and flow perturbation characteristics. In general, a modification behind the center of lift will increase stability; conversely, one forward will decrease stability. Increased stability results in an aircraft that responds more sluggishly, with higher control forces for trim and maneuvering but with higher dynamic frequencies and more sensitivity to gusts. The opposite effects occur with decreased stability.

A modification ahead of or near a flight control surface can affect low- and high-speed control margins through vortex shedding onto the flight control surface. These effects can result in loss of control and are special concerns with the C–130 elevator. In flight test, the C–130A elevator was found to have a lack of effectiveness during landing. The chord was increased by 133 percent to correct this problem.

As previously mentioned, flutter, buffeting, and vibration can affect handling qualities. This is caused by the uncompensated motion of the flight control surfaces relative to the airflow. For instance, an elevator rotated upward is expected to cause an aircraft to climb. Deflection of the horizontal stabilizer caused by buffet, flutter, or vibration can result in the elevator providing a nose-down rotation. Asymmetric bending of the horizontal stabilizer from flutter, buffet, or vibration can cause a roll or yaw. In general, remedies for flutter, buffet, and vibration are also remedies for these types of handling problems. These are usually high-speed problems and rarely affect the C–130.

There are other problems related to buffeting. Shed vortices that cause buffeting can be helpful; for example, the C–130's overblown wing is created by propeller vortices. In terms of handling qualities, vortices can also worsen handling qualities. High-energy air striking the elevator on the bottom surface can cause an uncontrollable pitch increase. This could be especially critical during a C–130 assault takeoff or landing, or during a stall.

"Handling qualities include static stability, tail plane control margins, mass properties, and dynamic stability."

A condition related to buffeting, called blanking, is caused when the air flowing over an aerodynamic surface is reduced by an object forward of the aerodynamic surface. This can result in

an uncontrollable pitch situation. Good examples of this phenomenon are exhibited in the stall of high-tailed aircraft such as the C–141.

Air worthiness and operational considerations. The most important consideration is that a modification will not degrade current overall aircraft flying qualities. Secondarily, a modification should not significantly change the flying qualities. In the first case, the aircraft mission may be compromised by aggravating emergency and normal situations with bad flying qualities; in the second, an aviator must be retrained to cope with a change in the handling feel of the aircraft. Anything that decreases the elevator control margins is a potential problem on the C–130. If control margins are grossly affected, the aircraft can display an increased tendency to depart controlled flight.

"The most important consideration is that a modification will not degrade current overall aircraft flying qualities."

The normal corrective action for degraded flying qualities is to restrict the aircraft's envelope. Minor changes in handling qualities can be accommodated by training programs and new technical orders.

High-altitude handling qualities, especially those related to dynamic stability (Dutch roll and phugoid) have a direct impact on passenger and crew comfort and are critical to aircraft controllability. The C–130 is not equipped with a yaw damper (which compensates for dynamic stability problems). Although Dutch roll is not a current problem in the C–130, a significant modification aft of the center of lift could decrease the aircraft's dynamic yaw stability. Depending on its severity, this would cause an altitude restriction or require a change to the modification.

Stalls, Air Minimum Control Speed, and Dynamic Engine Failure

Rationale. Stalls, engine-out flight, and dynamic engine failure are primary concerns because of potential negative handling qualities. A modification not mounted on the wing is not expected to affect the lift of the wing, but the effect of the modification on the empennage could reduce control margins to the point at which the aircraft departs controlled flight. More specifically, during low-speed flight, the loss of elevator effectiveness because of blanking or buffeting could cause a pitch up of the aircraft or a deeper, less recoverable stall. Asymmetric shedding from the modification could result in yaw forces that increase the likelihood of a spin or that decrease control during an engine propulsion emergency.

During engine-out flight, the effect of a modification could be increasing control pressure and deflection requirements because of airloads against the modification with increasing yaw. In addition, the uneven effects of sideslip angles on a symmetrical modification will result in an asymmetrical load on the aircraft. These loads, dependent on airflow patterns, could be helpful or harmful.

Air worthiness and operational considerations. The C–130 is a four-engined aircraft that is capable of flight on three or even two engines. It is not uncommon

to experience engine failures during flight. In the last five years, two aircraft have experienced dual engine failures in flight and have safely recovered. In these situations, the safety of the aircraft is dependent on control margin and air minimum control speed. Any reduction in control margin increases the air minimum control speed and reduces the chance an aircraft can be safely recovered. Engines also tend to fail at high power settings (takeoff and landing, low speed); dynamic failures are grossly affected by control margin and by aircraft stability margins.

Although the C–130 is a very forgiving aircraft and easy to recover from a stall, stalls have been the cause of some C–130 mishaps. Two types of stalls are possible in a C–130: a normal wing stall and a rudder fin stall. In a wing stall, the aircraft angle of attack (AOA) exceeds the capability of the wing to generate lift. The wing loses lift and the aircraft stalls. Recovery is accomplished by releasing back pressure to decrease AOA and increasing engine power. If back pressure is not released, the stall can be exacerbated, which will result in an increased loss of altitude. The elevator is usually effective even after the wings have stalled. If airflow around the elevator prevents the pilot from rotating the aircraft to a lower AOA, the stalled condition will continue until the pilot can force the nose over, or the aircraft hits the ground. If while the aircraft is in a stall, and yaw is applied either through a modification's asymmetric vortex shedding or the rudder, the aircraft can spin. C–130s have spun; they do not recover!

A rudder fin stall is a medium-speed phenomena in which the aircraft vertical stabilizer is stalled. During normal rudder use, the rudder is self-centering due to air loads; force is required to yaw the aircraft. During a fin stall, the aircraft is flying sideways with a high rate of yaw; force has to be applied to the rudder to make the aircraft fly straight again.

Performance (Drag)

Rationale. The main effect on performance for nonengine modifications comes from changes in drag. Increases in drag can degrade an aircraft's mission capability by reducing airspeed, ceiling, range, payload, and increasing takeoff distance. Drag comes in three main varieties: parasite, induced, and Mach.

Parasite drag is the drag produced by the modification just because it is on the aircraft and is caused by profile and interference drag. Profile (a.k.a. form) drag is caused by the air hitting the modification—skin friction and pressure. Interference drag is the drag caused by flow-field interference from interactions of the surfaces near and connected to the modification. In subsonic flow, interference and pressure patterns can move forward of the surface. Parasite drag increases with increasing airspeed.

"Increases in drag can degrade an aircraft's mission capability by reducing airspeed, ceiling, range, payload, and increasing takeoff distance."

Induced drag is caused by the creation of lift. Vortex propagation from a structure is basically caused by the lift induced by the structure. These vortices change surface pressure distributions and cause an increase in drag. These vortices result

in the previously mentioned buffet. Induced drag is an inverse function of airspeed; it is the greatest at low airspeed.

Mach drag is mainly seen at the C–130 propeller, although it is possible at high speed on curved surfaces or in the engine flow field. Mach drag is caused by air flowing over a surface near Mach 1. Mach drag is what causes the controllability, noise, and vibration problems associated with a runaway prop on a C–130. Mach drag is rarely a problem on the C–130, but its effect is many times greater than that of induced or parasite drag.

"Mach drag is what is what causes the controllability, noise, and vibration problems associated with a runaway prop on a C–130."

If an aircraft's performance parameters vary from its baseline by a cumulative 5 percent, the mission design series (MDS) must be appropriately performance tested to produce updated performance charts. The aircraft's capabilities are defined in the performance charts. For example, an aircraft is charted to take off in 2,900 feet, but it really takes 3,050 (about 5 percent more) feet following a modification. Unless the aircraft performance data is updated to reflect the change, that aircraft may crash the next time the crew tries to perform a maximum effort takeoff from a 3,000-foot dirt strip. There is no leeway or forgiveness in the charts.

Air worthiness and operational considerations. Many variants of the C–130 are performance limited. The gunships (AC–130H/U) are limited by drag to their current firing altitudes. Increased drag may result in moving them lower into the threat, thus negating survivability improvements. The Talons (MC–130E/H) are primarily terrain-following (TF) aircraft whose TF flight profile calculations and commands are dependent on their drag. Increases in drag have the potential to significantly affect TF capability. Further, significant increases in drag will reduce top and cruise airspeed, ceiling, range, payload, and will increase takeoff distance. All these effects are capable of degrading mission capability and must be investigated when making external modifications.

Flow Field

Rationale. Dropping items from aircraft creates a dual hazard: one to the aircraft, the other to the dropped item. Whenever an external store (which can be jettisoned or dropped from an aircraft) is developed, it must go through a certification process (Seek Eagle). This is because it is not uncommon for streamlined bombs, even in benign conditions, to strike aircraft when they are released. Tactical airlift aircraft are a complication in the carriage of external weapons. In this case, fragile personnel and very heavy objects (>44,000 lb) are dropped from the back and, in the case of personnel, from the side doors. The complexities of this, in terms of flow field, are manifold, from the unmodelable (and in many cases unknown) interactions of a 44,000-lb road grader to the unretrievable (due to air loads) hung paratrooper.

Extensive airdrop tests and certifications are made on airlift aircraft prior to the first real (human or cargo) drop. Safety is the driving concern of these tests with

two objectives in mind: first, to prevent damage to the aircraft because a load doesn't exit properly (hangs, gets stuck, slow release, etc.) or because it strikes the aircraft, and second, to prevent damage to the load.

Modifications to an aircraft affect flow fields, as mentioned above. The other sections described how these flow fields can affect the aircraft itself. In the case of airdrop, these flow fields interact with the objects moving through the field. Objects in an airstream create flow fields, which affect the aircraft and airdrop items both ahead and behind them. This is because subsonic flows create pressure patterns (effects) ahead of the aerodynamic structure they are striking. This is why Pitot tubes on most very fast aircraft are placed on the tip of the nose and away from the aircraft. On slower aircraft, the forward progression of the pressure patterns (flow fields) is less; however, the larger the object and the greater its flatplate surface, the greater the forward effect. The Pitot system on the MC–130H and the gunship required extensive testing and recertification because of the changes in the design from the MC–130E and AC–130H.

Air worthiness and operational considerations. If the load doesn't exit properly, the aircraft can be lost. This has occurred to C–130s on four separate occasions in the past 20 years. If the load is damaged during drop, the mission is a failure. The MC–130H is a special case among C–130s since its nose radome causes the airflow around the paratroop doors, the cargo ramp, and the cargo door to be at a higher speed than on a slick C–130. Drop tests during development proved the design, which is significantly different than a regular C–130. In addition, the MC–130H is capable of airdrops up to 250 knots indicated air speed (KIAS); the "green" C–130 is normally limited to 150 KIAS. The AC–130U also has flow-field considerations because the primary method of in-flight egress is the right rear paratroop door. This door has been provided with an extended air deflector to allow safe egress.

Forward field effects from a large modification aft of the troop doors could greatly affect flow patterns around the door. This could produce problems for paratroopers by causing them to hit the side of the aircraft, by preventing D-bag recovery, and by preventing recovery of a hung paratrooper. Similar effects could prevent successful egress from an AC–130.

"The massive change in the center of gravity during a heavy airdrop makes for an unflyable aircraft if the load hangs."

Aft flow-field effects from a modification forward of the ramp and door could cause similar problems for paratroopers exiting the ramp and door, but could also affect the airdrop of heavy equipment and container delivery system loads. Heavy airdrops all require parachutes to deploy for extraction. Delays in parachute opening caused by flow-field effects could increase the time for load extraction, causing off-target drops or hung loads. The massive change in the center of gravity during a heavy airdrop makes for an unflyable aircraft if the load hangs. A hung 44,000-lb load would stand a C–130 on its tail. Increases in air velocity can cause deployment and extraction chutes to blow out, causing delayed or hung loads.

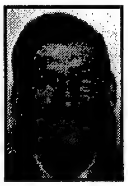
Electromagnetic Interference and Electromagnetic Compatibility

Rationale. Electrical and magnetic fields occur around the wiring (radiated) in an aircraft, and equipment may output interfering signals directly on common wiring such as the power lines (conducted). Dependent on the voltage, amperage, filtering, and shielding, the interference levels will vary and may prevent other electrical equipment from working correctly.

Air worthiness and operational considerations. The most commonly affected part of the aircraft is the navigation equipment. Air Force aircraft are not shielded in accordance with Federal Aviation Administration requirements, so it is not uncommon for portable electronic devices such as cassette recorders and compact disc units to cause problems with the navigation repeaters and the intercom. New equipment installations must always be tested for electromagnetic interference and electromagnetic compatibility (EMI/EMC) on each mission design series; the equipment itself should have been tested for EMI/EMC compliance during its development phase. The reason for this is that the wiring in each MDS is different. In one case, the modification wiring may be next to a high-frequency radio wire bundle; in another, it might cross a transponder lead. It is also imperative that the wiring be consistent on each aircraft within an MDS, so that the interference issues are the same and only one aircraft of a given MDS needs to be checked.

Summary and Conclusions

It is clear that even a simple modification to an aircraft can result in disastrous consequences if adequate testing is not accomplished. It should also be apparent that such simple modifications require a complex analysis of the effects of the modification. When planning, developing, and producing modifications, keep these concepts in mind, and realize that the C–130, in all variants, is a relatively uncomplicated aircraft. When modifications are required for an aircraft which is fly-by-wire, control-by-wire, or significantly dependent on software and software-based systems for basic flight, the problems described can be magnified significantly in their complexity and effect.



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ACQUISITION REFORM: *THEORY AND EXPERIMENTAL EVIDENCE FOR TOURNAMENT SPONSORS*

Lt Col Richard Fullerton, USAF, Bruce G. Linster, Michael McKee, and Lt Col Stephen Slate, USAF

Billions of dollars worth of contracts are awarded to the winners of research and development competitions annually. In the past decade a number of theoretical papers have been published on the use of research tournaments to induce optimal research efforts. This paper gives a general overview of decision-making experiments conducted to test theoretical predictions in a controlled setting. Our results indicate that carefully designed research tournaments can be highly effective at promoting research efforts as predicted by theory.

Recent General Accounting Office (GAO) studies have identified acquisition reform as one of the Pentagon's highest priorities (GAO, 1997). With dwindling defense budgets, the Department of Defense (DoD) plans to defray the cost of force modernization with the savings from acquisition reform. One area where savings might accrue is DoD-sponsored research tournaments. A recent paper by Curtis Taylor (1995) demonstrates potentially huge implications for how the federal government can save money. By sponsoring a research tournament, the government can induce the efficient amount of research and development effort from industry without the need for costly regulatory oversight—oversight which the Carnegie Commission (1992) estimates costs the DoD about 40 percent of its acquisition budget.

Research tournaments have played an important role in the economic growth of nations since the Industrial Revolution. For example, the golden age of steam locomotion was spawned by a research tournament spon-sored by the Liverpool and Manchester Railway in 1829.[1] More

recently, research tournaments have been used to create a variety of products ranging from fuel-efficient refrigerators (Langreth, 1994) and digital televisions ("HDTV," 1993), to high-tech fighter aircraft for the military (Schwartz, 1991). Today, scientists and lawmakers are even considering the use of a research contest to propel the development of the first manned space mission to Mars.[2]

Most recently, Jacques S. Gansler, the Under Secretary of Defense for Acquisition and Technology, discussed the need to "continue and greatly expand our efforts to implement a 'revolution in business affairs' within DoD..." (1998, p. 8). Gansler's keynote address on "Realizing Acquisition Reform" discusses five areas that require specific attention. Many of these specific recommendations are inherent qualities of sponsored research tournaments. In the acquisition arena, research tournaments allow DoD to be "another buyer of high-quality, high-performance, differentiated items" by allowing for greater competition, less oversight, and more flexibility in the acquisition of new products for mission requirements (Gansler, p.11).

"In fact, the most prolific sponsor of research competitions is the federal government, and in particular the Department of Defense."

In fact, the most prolific sponsor of research competitions is the federal government, and in particular the Department of Defense. Each year the federal government awards billions of dollars worth of contracts to winners of competitive research and development competitions.[3]

Taylor (1995) provided a theoretical model for evaluating the effect of the parameters (competitors and duration) of these research tournaments. Fullerton and McAfee (1996) extended this framework to tournaments with heterogeneous contestants. Taylor proved that, by limiting the number of competitors in a research tournament and charging each competitor an entry fee, the tournament sponsor could inspire an efficient amount of research effort. Fullerton and McAfee show that with heterogeneous competitors, sponsors can induce the best-qualified competitors to enter the competition by conducting specialized all-pay entry auctions. Thus there is a small but growing collection of literature on the theory of research tournaments, as well as some empirical evidence.

The focus of this investigation is Taylor's original model. In it, M risk-neutral firms and T periods are available for each firm to conduct research. Each period, firms pay research cost C to obtain a single independent draw, x, from the innovation distribution, $F(x)$. Research is performed with recall, so that at the end of T periods each firm submits its best innovation to the tournament sponsor. Taylor proved that the optimal strategy of firms competing in a research tournament is conducting research until drawing an innovation worth at least some value "z" and then stopping. This stopping rule strategy dominates all other strategies, and is what we tested in our laboratory setting.

Although the economic intuition behind the effectiveness of tournaments is straightforward, the empirical calculations required to compute equilibrium strategies are complex. The empirical question is whether individuals or firms are able to

compute these strategies. We conducted a series of laboratory experiments in which the subjects chose a search strategy in a research and development (R&D) setting to answer this question. The experiments we conducted tested Taylor's research tournament theory by examining whether subjects in a controlled economic laboratory setting can be induced to expend the predicted amount of R&D effort in an essentially unregulated environment.[4]

Despite the complexity of computing the equilibrium research strategy, we find the overall level of effort expended and the winning innovations are remarkably close to the predictions of Taylor's model. Although some subjects overinvest in R&D and others underinvest, the majority of subjects adopt a stopping rule strategy when conducting research, as predicted by Taylor. This stopping rule strategy is simply that a competitor will cease conducting R&D once a certain level of innovation is reached, as opposed to other strategies, to include continuous research throughout the tournament regardless of the level of innovation attained. Indeed, we find few instances of internal inconsistencies. We also find that the average behavior of subjects is close to that predicted by Taylor's theory. As a consequence, the R&D tournaments achieve very high levels of efficiency in the laboratory. The implication of our study is that the government needs to carefully monitor the length of the tournament and the number of competitors in any procurement action. The oversight should be aimed at achieving the optimal level of competition between firms, and not at the effort level of the individual firms. This shift away from a micro-oriented regulatory strategy to a more macro- or industry-oriented strategy should result in substantial savings in the overall procurement budget, since less detailed oversight will be required.

Experimental Design

To test Taylor's model, we designed a series of experiments to determine if subjects individually, or as a market, provide results similar to those predicted by the theory. The experiments were conducted at the University of New Mexico's computerized experimental economics laboratory with subjects recruited from undergraduate social science classes. Each subject was assigned a computer terminal, and the laboratory was designed to limit the subject's view to his or her own terminal. This helped to ensure each subject's response was independently determined. Computerization of the experiments allowed for immediate feedback for the subjects and this feedback enhanced subject understanding of the actions required.

"...the R&D tournaments achieve very high levels of efficiency in the laboratory."

As the experiment began, subjects received a set of written instructions explaining that they would be participating in a market where the task was to decide whether to pay for a draw of a random number in an effort to win a prize. At the start of each round, subjects were given an endowment of francs (the laboratory currency) sufficiently large to ensure they could take a draw every period of the round without exhausting their endowment. Each draw generated a value

between 0 and 999, with each number equally likely. Subjects were told the maximum number of draws in each round that could be taken, the cost of taking a draw, and the number of competitors in their group. At the end of each round, the player in each group with the highest draw was awarded the specified prize. A subject's total payoff at the end of the experiment was equal to the sum of the prizes won in each round plus all unspent francs remaining from the endowment.

"In the context of a research tournament, choosing to make a draw corresponds to conducting research at a constant cost-per-unit."

The subjects did not know how many rounds would be conducted during the session. Finally, they were told they would be assigned to a different group each round, and at the end of the session their francs would be converted to dollars at a stated exchange rate.

In the context of a research tournament, choosing to make a draw corresponds to conducting research at a constant cost-per-unit. Beforehand, the outcome of the research process is unknown, but the distribution from which the research results will be drawn is common knowledge in Taylor's model. Each draw corresponds to the realized level of research for that period, and the group high draw is the level of the winning innovation for that round. Again, a round comprises several periods in which research can be conducted, but each round is a separate, independent research tournament. While we realize that the assumptions of Taylor's model are simplistic, our purpose is to give the predictions of his model a chance at succeeding before violating those assumptions and creating a much more complicated and difficult experiment. Certainly varying the cost of research across firms, across time, and allowing the distribution of winning innovations to remain unknown would add a greater element of realism and deserves greater study, both theoretically and in the laboratory.

Experimental sessions covering five treatments were conducted. A session refers to subjects interacting in the laboratory, whereas a treatment refers to the specific parameters subjects face in a given session. A total of 103 subjects participated in these experiments and no subject participated in more than one session. Across sessions, we varied the number of competitors in each group, the maximum number of draws, and the prize (in francs) awarded to the competitor—with the largest draw in each group for each round.

Empirical Results

In this section we subject our data to various tests at the market and individual level. We find the subjects do not individually employ the symmetric equilibrium stopping strategies predicted by Taylor. Some individuals behave as if their z-stop is below the predicted level while others behave as if it is above. However, we find that the aggregate behavior in each tournament treatment is generally consistent with the predictions of the theory, and that the majority of subjects do appear to be following a stopping rule strategy.

In *every* cross-comparison of treatments, the mean winning innovation and

the mean research-to-prize ratio moved in the direction predicted by Taylor's theoretical model. This is not to say that each individual subject accurately computed and employed the correct z-stop strategy, but rather that, on average, the winning innovation in each tournament and each group's cumulative research effort moved in the proper direction. The theory predicts virtually identical levels of winning innovations, and means that research-to-prize ratios increase across certain treatments but decrease across others. This is precisely what we have observed. At the market level, the data are qualitatively consistent with the predictions of Taylor's model. Thus, statistically, it appears that Taylor's model is internally consistent. By this we imply that *relative to other treatments,* when the mean level of the winning innovation was predicted to rise as a function of changing one of the parameters, our experimental data are consistent with the prediction. Moreover, changes in the distribution of winning innovations across experimental treatments are not only in the proper direction, but they are also statistically significant.

Taylor's theoretical predictions arise from the argument that the competitors adopt the z-stop strategies constituting the symmetric equilibrium. Using our data, we can estimate the implicit stopping rule that is generated by a subject's observed behavior. For example, if a subject uses a stopping strategy, the imputed z-stop may be estimated. Therefore, by calculating the average number of draws in our experimental sessions, we can estimate the z-stop that would generate the same number of experimental draws. The imputed z-stop strategies are close to the predicted levels for all treatments except one.[5] This particular treatment has both a large number of competitors as well as a long time horizon. As we shall see repeatedly, this combination of conditions exhibits more violations of the theory than do settings in which the tournament is short-lived or in which there are fewer competitors.

In addition to predicting a stopping rule, the theory also predicts a level of draw (research) activity. In all treatments except one, the subjects made slightly fewer draws than the level predicted by Taylor's theory. This result supports the conjecture that a large tournament (with many players invited) that continues for several periods may lead to excessive expenditures on R&D.

"In every cross-comparison of treatments, the mean winning innovation and the mean research-to-prize ratio moved in the direction predicted by Taylor's theoretical model."

The variance in subject behavior is more likely to create problems for the tournament sponsor when the tournament is permitted to continue for several periods. With longer tournaments the potential exists for the subjects who overshoot the theoretical z-stop to overwhelm those who undershoot. This overshooting phenomenon has some serious implications if it bears out in real-world research tournaments. In particular, sponsors may risk driving some of their potential R&D firms to bankruptcy if they sponsor tournaments with too long a time horizon or too many competitors.

Conclusions

The focus of our experiments was to evaluate the fixed-prize mechanisms as a means to obtain a given quality of research at as low a cost as possible under various market conditions. Overall, the results appear to support the theory. At the market level, the winning research product and level of research effort tended to be close to the theoretical prediction. In addition, the majority of our subjects appear to employ a stopping rule strategy rather than a rule of thumb. However, instead of observing a uniform level of effort across all competitors, as the symmetric equilibrium would predict, the research strategies varied significantly across subjects.[6]

This variance tended to affect the aggregate results of our experiments. When there were only two periods for research, there tended to be less total research than predicted because there was not enough time for those who did the most research to make up for those who did very little. In the longer research tournaments with several competitors, we tended to see levels of research at or above the predicted amounts. Here, the high-effort competitors had ample research time to make up for the low-effort players, and the result was higher levels of winning innovations and in some instances "excessive" levels of aggregate research, which reduced the tournament efficiency.

The effect of additional participants and more research periods can potentially be substantial. The evidence supports the intuitive notion that if these parameters are increased arbitrarily, participants in long research tournaments may lose money because of excessive competition. In the long run, this would be self-correcting because either the competitors would adjust their behavior and collectively engage in less research, or some competitors would be driven out of the market and aggregate research would naturally decline due to fewer number of competitors. It may not be in the sponsor's long-term best interest for this to happen; judicious selection of the prize, the time horizon, and the number of competitors seems to be indicated.

There is still much to be learned about how individuals and firms respond to research tournaments. We hope to continue our investigation into research tournaments by varying parameters and the assumptions of Taylor's model and encourage others to do likewise. However, the preliminary results provide some evidence that fixed-prize tournaments are highly effective and efficient.

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ENDNOTES

1. The contest, known as the Rainhill Trials, was used to select an engine for the first-ever passenger railroad in Britain. The £500 first prize was won by George and Robert Stephenson, who built the Rocket, which attained a top speed of 46 km/h. See Day (1971) for details about the evolution of steam locomotives.

2. The mission to Mars contest was worked up for a member of Congress by the executive chairman of the National Space Society, Robert Zubrin. The proposal is a series of contests with prizes in the $1 billion range, culminating in a $20 billion first prize (Zubrin, 1996).

3. By law, federal agencies are required to conduct competitive procurements whenever practicable. For example, in 1991 the Air Force held a "fly-off" competition to select the new Advanced Tactical Fighter. Lockheed won that competition with its F–22, and won the production contract, which was estimated at the time to be worth more than $90 billion (Schwartz, 1991).

4. A far more rigorous treatment of the theory, statistical results, and testing, as well as a more complete description of our experimental design, is available upon request and will be published in an upcoming edition of *Economic Inquiry.*

5. For these tests we eliminated the rounds in which individuals did not make any draws. The justification for this is that these are simultaneous move games. That is, when an individual chooses a strategy, it is based on the expectation that the group is of the announced size. Thus, the strategy choice is unaffected by whether one or more competitors has decided to drop out.

6. Such variance in behavior has been observed in many other individual decision settings. Camerer (1995) reports several examples of experiments in which subjects systematically overstated risk while others understated risk. It is an interesting question whether markets correct such behavior or whether aggregating market observations merely masks it.

ASSESSING INDUSTRIAL CAPABILITIES FOR CARBON FIBER PRODUCTION

Frank T. Traceski

Analysis and evaluation of requirements and industrial capabilities are an important part of the defense system acquisition process. From providing milestone decision support on industrial and production issues to understanding and managing program risk, assessment of industrial capabilities provides for informed and realistic decision making on major defense acquisition programs. Carbon fiber is a key constituent of advanced composite materials used in many defense and aerospace systems. This paper assesses industrial capabilities for carbon fiber production, a sub-tier industrial sector critical to defense systems.

Carbon fibers are a key constituent in advanced composite materials, which are used in demanding defense aerospace applications. From military aircraft, such as the F–22, F/A–18, AV–8B, and B–2, to strategic missiles such as Trident II D5, to space launch vehicles, such as the Titan IV solid rocket motor upgrade, to satellite structures, carbon fiber composites are widely used for high performance applications because of their high strength, high stiffness, and low density. Because of the performance enhancements attributable to carbon fiber composites, these materials are characterized as militarily critical technology. This analysis was performed to assess the state of the carbon fiber industrial base.

Description of Carbon Fibers

Carbon fibers are high-strength, high-stiffness (elastic modulus) materials that are combined with a matrix material, most commonly an epoxy plastic, to form an advanced composite material. It is the combination of high strength, high stiffness, and low density that makes carbon fiber composites so appealing for many

demanding aerospace applications, where reduced weight is so important (Table 1) (ASM International, 1987). Some specialized carbon fibers are also useful because of their high thermal conductivity or extreme high-temperature performance. Because of their desirable engineering properties, carbon fiber composites are widely used in defense aerospace systems (Table 2).

Carbon fibers may be manufactured from polyacrylonitrile (PAN), petroleum pitch, or rayon precursor materials by high-temperature (2000 to 3500° F) carbonization or graphitization processes. The PAN-based carbon fibers are the dominant class of structural carbon fibers and are widely used in military aircraft, missile, and spacecraft structures. Pitch-based carbon fibers generally have higher stiffness and thermal conductivities, which make them uniquely useful in satellite structures and thermal management applications, such as space radiators and battery sleeves. Rayon-based carbon fibers used in carbon-phenolic composites have extremely low values of thermal conductivity, making them useful for rocket nozzle and missile reentry vehicle nosecones and heat shields.

CARBON FIBER DEMAND

Carbon fibers are considered dual-use, meaning that they are used in both

Definitions of Terms

Carbon fiber. Fiber produced by carbonizing precursor fibers based on PAN (polyacrylonitrile), pitch, or rayon. The term is often used interchangeably with graphite. Carbon fibers and graphite fibers are made and heat treated at different temperatures, however, and have different carbon contents.

Composite material. Product made by combining two or more dissimilar materials such as fibers and resins to create a product with exceptional structural properties not present in the original materials.

Continuous filament. Carbon fiber of small diameter and indefinite length (as compared to chopped fiber). Each type has different applications.

Modulus of elasticity. The physical measurement of stiffness in a material. A high modulus indicates a stiff material.

PAN (polyacrylonitrile). A polymer which, when spun into fiber, is used as a precursor material in the manufacture of PAN carbon fibers.

Precursor. The PAN, pitch, or rayon fibers from which carbon or graphite fibers are produced.

Tow. An untwisted bundle of continuous filaments, usually designated by a number followed by "k," indicating multiplication by 1,000 (e.g., 12k tow has 12,000 filaments).

Table 1. Typical Properties of Common Structural Materials

Material	Strength (ksi)[a]	Stiffness (Msi)[b]	Density (g/cm3)[c]
Metals			
Aluminum	80	10	2.76
Titanium	160	16	4.42
Steel	200	30	8.00
Composites			
Glass/epoxy	250	8	1.99
Aramid (Kevlar)/epoxy	190	12	1.38
Carbon (Graphite)/epoxy	215	21	1.55

[a] Thousands of pounds per square inch.
[b] Millions of pounds per square inch.
[c] Grams per cubic centimeter.

Source: ASM International (1987).

Table 2. Carbon Fiber Usage on Aerospace Systems

Weapon System	Carbon Fiber Type		
	PAN	Pitch	Rayon
Missiles			
Strategic	X	X	X
Tactical	X		X
Space			
Launch vehicles	X		X
Satellites	X	X	
Aircraft			
Fixed-wing	X	X	
Rotary-wing	X		

commercial and military applications. Demand varies significantly for PAN-, pitch-, and rayon-type carbon fibers because of the fibers' different physical properties, their use in different applications, and the manufacturing processes used in their production.

Recent figures (Table 3) released by the Suppliers of Advanced Composite Materials Association (SACMA, 1997) indicate that PAN carbon fiber demand has increased annually from 11 million pounds in 1991 to 26 million pounds in 1997. Commercial demand in the industrial, sports, and commercial aerospace sectors are the major market drivers, and have sustained this industry's growth in recent years. A major commercial application is the use of carbon fiber for the tail fin composite structure for the Boeing 777. In contrast, defense demand for PAN carbon fibers was estimated in 1995 to be about 1 million pounds, or about 5 percent of the overall market.

"The Department of Defense (DoD) continues to foster competition and innovation in carbon fiber development."

The Department of Defense (DoD) continues to foster competition and innovation in carbon fiber development. For example, the Naval Air Systems Command is developing an acquisition strategy for naval aircraft (e.g., the F/A–18E/F and the V–22) to qualify two sources of PAN carbon fiber for a broad array of structural applications. As of the end of 1997, the PAN carbon fiber industry had grown to a $600 million-per-year business.

Official figures for pitch-based carbon fiber usage are not available, but it is estimated that demand for these specialized materials is much less and is measured in the thousands as opposed to millions of pounds. The major market for pitch carbon fibers is for aircraft brake discs and other carbon-carbon composite applications. Satellite manufacturers also use pitch-based fibers for their high modulus and high thermal conductivity for heat dissipation in space radiators or electronic enclosures. Engineers at satellite manufacturers have reported typical lot buys of a few thousand or several hundred pounds.

Although demand for pitch-based carbon fibers is much less than for PAN carbon fibers, there will likely be increased use of pitch-based carbon fibers in thermal structural applications. In general, pitch fibers are much more expensive (Table 4) because of the energy-intensive, higher temperatures required in their manufacture and their lower demand ("Update: New Carbon Fiber," 1998; Amoco, 1998). In consequence they are only used where lower-cost PAN or other fibers do not meet a particular application's engineering requirements.

Carbon fibers produced from rayon precursor are used almost exclusively in ablative applications, such as reentry vehicle nosetips, heat shields, and solid-rocket motor nozzles and exit cones. Rayon-based carbon fiber-phenolic composites can withstand the high temperature and erosive gases of solid-rocket motor operation and the high temperatures generated by aerodynamic heating on missile reentry systems. During the past 10 years, demand for annual production of aerospace-grade rayon has varied from 100,000 pounds to more than 1 million pounds due to DoD and National Aeronautics and Space Administration

Table 3. Worldwide PAN Carbon Fiber Shipments, 1991-1997

Year	Pounds	U.S. (millions of $)*
1991	11,442,059	298.80
1992	13,002,812	374.10
1993	14,598,544	384.90
1994	17,425,452	461.40
1995	19,714,671	464.80
1996	20,672,741	489.24
1997	25,964,530	621.41

* Dollars are current year and have not been adjusted for inflation.

Source: Suppliers of Advanced Composite Materials Association (1997).

Table 4. Cost of Carbon Fibers

Fiber	Tensile Modulus (Msi)	Thermal Conductivity (W/mK)	Cost ($/lb)
PAN-based carbon fiber[a]			
Heavy tow (48–320K)	33–35		8–11
Aerospace grade			
Standard modulus (12K)	33–35		18–20
Intermediate modulus (12K)	40–50		31–33
High modulus (12K0	50–70		60–65
Ultrahigh modulus (3K, 6K, 12K)	70–140		120–900
Pitch-based carbon fiber[b]			
P–55	55	120	55–80
P–120	120	640	800
K–1100		1100	1,750

[a] Source: High Performance Composites 1999 Sourcebook.
[b] Source: Amoco (1998).

Table 5. Carbon Fiber Producers for Aerospace Systems

Manufacturer	Carbon Fiber Type	Principal Fibers Used on Aerospace Systems
Amoco	PAN	T300,T650
Amoco	Pitch	P120, K1100, K800X
Hexcel	PAN	AS4, IM6, IM7, UHM
Toray	PAN	T300, MJ series
Toho	PAN	G30, G40, G50 series
Mitsubishi	Pitch	K13C2U
Nippon	Pitch	XN and YSH series
NARC	Rayon	No longer produced

(NASA) stockpiling and usage fluctuation. After assessing rayon fiber industrial capabilities in 1997, DoD and NASA made a deliberate policy decision to buy out and stockpile their rayon fiber needs for the next five years. As of this writing, there is no immediate demand for new aerospace-grade rayon production.

Carbon Fiber Producers

Major producers of carbon fibers for aerospace systems are identified in Table 5, along with the fiber designations of their products. The list is limited to fibers that are widely used in military and aerospace applications. As mentioned above, PAN carbon fibers are the most widely used and deserve closer analysis.

To assess the trend in industrial capabilities for PAN carbon fiber production, one must look back at worldwide carbon fiber production capacities in 1989 and 1991 (for which data were available) to make a comparison to current production capacity (1998). Table 6 lists the major carbon producers in 1989 and 1991 and their reported production capacities (Hercules, 1991; Lin, S-S., 1992). Table 7 documents results of a recent survey of current PAN carbon fiber producers (Traceski, 1998), including plant locations and current annual capacities. The table also groups producers into two categories based upon what form of product (i.e., small or large tow) they produce. (A tow is an untwisted bundle of continuous filaments.) Generally speaking, the smaller tows have been qualified for military aerospace applications.

In 1989 worldwide production capacity for PAN-based carbon fibers was 19 million pounds. By 1991 capacity had increased to 26 million pounds. In 1998 production capacity is 65 million pounds, having more than tripled since 1989. The table comparisons also reveal some name

Table 6.
Worldwide Production Capacity for PAN-Based Carbon Fibers, 1989 and 1991

Producer	Production Capacity (1989, lbs per year[a])	Production Capacity (1991, lbs per year[b])
United States		
Hercules	3,000,000	3,850,000
BASF (Celanese)	990,000	3,267,000
Amoco (UCC)	880,000	2,200,000
Courtaulds-Grafil	660,000	792,000
Akzo	990,000	792,000
Stackpole (Zoltek)	130,000	242,000
BP	260,000	88,000
Avco	150,000	44,000
Asia		
Toray	3,300,000	4,950,000
Toho	3,100,000	4,444,000
Asahi Nippon Carbon	990,000	990,000
Mitsubishi	350,000	1,100,000
Nikkisso	130,000	
Taiwan Plastics		506,000
Korea Steel		330,000
Europe		
Courtaulds-Grafil	790,000	770,000
Soficar	990,000	660,000
Enka/Akzo	1,100,000	770,000
R.K. Carbon	220,000	506,000
Sigri	220,000	55,000
Other	770,000	
Total	**19,020,000**	**26,356,000**

[a] Hercules (1991).
[b] Lin, S-S. (1992).

Table 7.
Worldwide Production Capacity for PAN-Based Carbon Fibers (1998)

Manufacturer	Facility	Capacity (lb)
Aerospace Grade Carbon Fiber (small tow)		
Amoco	Greenville, SC	2,200,000
Amoco (BASF, 1993)	Rockhill, SC	2,000,000
Hexcel (Hercules, 1996)	Magna, UT	4,500,000
Toho	Mishima, Japan	7,400,000
Toho	Oberbruch, Germany	3,900,000
Toray	Ehime, Japan	9,400,000
Toray	Abidos, France (SOFICAR)	1,600,000
Toray	Decatur, AL (Monsanto)	3,600,000
Mitsubishi-Grafil	Toyohashi, Japan	5,500,000
Formosa Plastics	Taiwan (Tairylan)	4,000,000
Commercial Grade Carbon Fiber (large tow)		
Zoltek	St. Louis, MO	3,500,000
Zoltek	Abilene, TX	3,000,000
Zoltek	Nyergesujfalu, Hungary	2,000,000
Akzo Fortafil	Rockwood, TN	5,000,000
Mitsubishi-Grafil	Sacramento, CA	2,000,000
SGL Carbon (RK Carbon)	Inverness, Scotland	3,000,000
SGL Carbon	Meitingen, Germany	600,000
Aldila	Evanston, WY	2,500,000
Total		**65,700,000**

All capacities are nameplate capacities (i.e., the optimum amount for which a line is designed).

Effective capacity, which takes into account downtime and product mix factors, etc., is generally proprietary.

A "tow" is an untwisted bundle of continuous filaments, usually designated by a number followed by "k," indicating multiplication by 1,000 (e.g., 12k tow has 12,000 filaments).

Standard aerospace-grade structural carbon fiber tows are 3k, 6k and 12k.

Larger tow products are generally used in commercial, nonaerospace type applications.

Zoltek produces 48k, 160k and 320k tows.

Akzo Fortafil produces 50k tow. An additional 3.3 million lb capacity to be on-line by December 1998.

Grafil produces 1k, 3k, 6k, 12k and 24k tow in Japan and 12k, 24k and 48k tow at Sacramento.

SGL Carbon produces 60k and 320k tow. An additional 3 million lb capacity to be on-line by December 1998.
Aldila produces 50k tow, primarily for golf shafts.

Source: Traceski, F. (1998).

Table 8.
Worldwide Production Capacity for Pitch-Based Carbon Fibers (1991)

Manufacturer	Trade Name of Fibers	Capacity (ton/year)	Capacity (lb/year)
Amoco	Thornel	230	506,000
Kureha Chemical	Kureha	900	1,980,000
Mitsubishi Chemical	Dialead	50	110,000
Nippon Oil	Granoc	50	110,000
Nippon Steel		12	26,400
Osaka Gas	Donacarbo	300	660,000
Petoca	Cabonic	12	2,400
Tonen	Forca	12	2,400

Notes:
Kureha and Osaka Gas produce short fibers, which have different applications than do continuous fibers.
In 1991 total capacity for continuous pitch fibers only was 366 metric tons or 805,200 pounds.
Petoca and Tonen halted pitch fiber production in 1992 and 1993, respectively.
Data Source: Lin, S-S. (1992).

changes due to various consolidations, acquisitions, and restructurings in the carbon fiber industry that took place between 1989 and 1998. Notably, Japanese Toray and Toho are the world's leading producers of PAN carbon fibers, with annual production capacities of 14.6 and 11.3 million pounds, respectively. U.S. companies Hexcel and Amoco each have annual capacities of more than 4 million pounds.

Worldwide annual production capacity for continuous pitch-based carbon fibers has been and continues to be significantly less than that for PAN carbon fiber. In 1991 there were six companies producing continuous pitch-based carbon fibers (Table 8) (Lin, S-S., 1992). In 1998 there were only three companies (Table 9) (Traceski, 1998). Amoco remains the only U.S. company producing pitch-based carbon fibers, with a current annual nameplate capacity of approximately one million pounds. Mitsubishi and Nippon are the two principal Japanese competitors. The Mitsubishi Chemical plant in Sakaide, Japan, has a capacity of approximately 1.1 million pounds per year. Nippon Graphite Fiber Corporation has a plant in Hirohata, Japan, that has a nameplate capacity of 264,000 pounds.

Production capacity for aerospace-qualified rayon fiber is virtually nonexistent. Up until October 1997, the sole

Table 9.
Worldwide Production Capacity for Pitch-Based Carbon Fibers (1998)

Principal Supplier	Facility	Capacity (lb/year)	Tow Sizes
Amoco	Greenville, SC	1,000,000	2k
Mitsubishi Chemical	Sakaide, Japan	1,100,000	2k, 10k
Nippon Graphite Fiber	Hirohata, Japan	264,000	0.5k, 1k, 2k, 3k, 6k
		2,364,000	

Notes:

All capacities are nameplate capacities (i.e., the optimum amount for which a line is designed).

Effective Capacity, which takes into account downtime and product mix factors, etc., is generally proprietary.

Nippon Graphite Fiber Corp is a joint venture company wholly owned by Nippon Oil and Nippon Steel, having undertaken their pitch fiber businesses in 1995.

Source: Traceski, F. (1998).

qualified source for aerospace-grade rayon fiber was North American Rayon Corporation (NARC) of Elizabethton, TN. The NARC ceased production because it had no current orders or promises for future orders. NARC had an annual capacity of approximately 2.5 million pounds of rayon fiber. Other unqualified sources of aerospace-grade rayon are Grupo-Cydsa (Monterrey, Mexico), Akzo (Obernburg Plant, Germany), Lenzing (Lowland Plant, TN), and Courtaulds (Axis Plant, AL). There is no current qualified U.S. producer of rayon fibers for aerospace use. Any new rocket or missile system will be faced with either qualification of a new rayon fiber or the use of some alternative material (such as PAN fiber) or an alternative design able to meet the requirements of extreme high-temperature performance for nozzle applications. Qualification of PAN fiber appears to be the preferred program approach at present.

Industry Consolidation and Restructuring

In recent years, the carbon fiber industry has undergone its share of consolidation and restructuring through various acquisitions. In the PAN carbon fiber industry, Amoco purchased BASF's manufacturing plant and equipment at Rock Hill, SC, in 1993. Hexcel acquired the Hercules PAN carbon fiber business at Salt Lake City, UT, in 1993. Zoltek bought equipment from Stackpole and Courtaulds, and RK Carbon was sold to Sigri Great Lakes Carbon (SGL).

Significant changes have also taken place in the pitch carbon fiber industry. Japanese producers Petoca and Tonen exited the pitch fiber business in 1992 and 1993, respectively. In 1995 Nippon Oil and Nippon Steel formed a joint venture company, known as Nippon Graphite Fiber Corporation, wholly owned by these two parent companies.

Industrial Capabilities Assessment

From an assessment of worldwide industrial capabilities for carbon fiber production, one can make the following observations:

PAN-based carbon fibers. Annual worldwide demand for these fibers increased from 1991 to 1997 and reached 26 million pounds. Annual worldwide production capacity now exceeds 65 million pounds, with Japanese Toray and Toho the leading producers. Defense needs make up only a small percentage of the annual demand for carbon fibers; commercial applications are the principal market.

Pitch-based carbon fibers. Research and development of pitch-based carbon fibers is resulting in their increased use in spacecraft structural and thermal management applications. There is only one U.S. supplier (Amoco) of these fibers. Mitsubishi and Nippon are the leading Japanese suppliers.

Rayon-based carbon fibers. There is no current U.S. supplier of rayon fibers for aerospace applications. Future systems will be forced to qualify alternative materials or new rayon fibers to meet their needs.

Summary

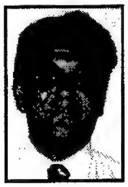
Assessment and evaluation of carbon fiber industrial capabilities reveal that this critical sub-tier industry (with the exception of rayon) is growing despite reductions in defense aircraft and missile procurements in the 1990s. Analysis of the worldwide carbon fiber industry indicates that demand for carbon fibers has increased over the past several years, as did production capacities. Carbon fiber production is one example of dual-use production where commercial products and processes have not only sustained the industry, but also are now driving new development, despite defense cutbacks.

Specifically, the PAN carbon fiber industry has grown into a $600 million-per-year business. Worldwide competition between major producers (Hexcel, Amoco, Toray, and Toho) continues to push innovation and new fiber development.

The pitch carbon fiber industry, although much smaller, maintains markets in aircraft brakes and satellite applications. Competition between producers (Amoco, Nippon, and Mitsubishi) is spurring new fiber development. Satellite manufacturers are exploiting these fibers for increased system performance.

"Research and development of pitch-based carbon fibers is resulting in their increased use in spacecraft structural and thermal management applications."

There is no current U.S. producer of carbonizable rayon fiber. New systems requiring high thermal performance will be faced with qualifying new rayon precursor materials or designs, or reconstituting a domestic industrial capability to manufacture aerospace-grade rayon.



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OUTSOURCING AUTOMATIC DATA PROCESSING REQUIREMENTS AND SUPPORT

William N. Washington

Outsourcing has become an increasingly popular way to reduce costs and focus operations upon the main objectives of an organization. This article considers outsourcing in general, and automatic data processing (ADP) outsourcing in particular. Private industry and government each have their respective successes and failures; lessons learned from them should guide outsourcing decisions. In general, outsourcing, especially of ADP processes, has been popular, but it should not be expected to produce savings in all instances; rather, most gains with outsourcing have been quality improvement. With foresight and proper structuring of the contract, more successes will come.

Outsourcing is taking a more prevalent role both in government and corporate strategies in the current environment of fiscal constraint. As Secretary of Defense William S. Cohen has recently stressed (Cohen, 1997), in order to afford the future modernization of our force structure, we need to reduce the current cost of our existing support structure to "make it perform better at less cost by harnessing the revolution in business affairs." He goes on to say "we still do too many things in-house that we can do better and cheaper through outsourcing." This sentiment was previously advocated by the Defense Science Board (1996), and is also present in new House and Senate bills, which seek to require privatization of nongovernmental functions, unless they can be shown to be less expensive in-house (Brewin, 1997; "OMB favors," 1997; and Harris, 1997).

What is outsourcing? It has been defined in a number of ways, but the simplest definition would probably be that outsourcing is a contractual agreement between a customer and one or more suppliers to provide services or processes that the customer is currently providing internally. Its intended purpose is to cut costs

and improve quality though the use of "experts in the area" to perform those functions. This potential has been realized by the large corporate outsourcing stories that have unfolded in the past several years. Such companies as American Airlines, British Petroleum, General Dynamics, Kodak, McDonnell Douglas, Xerox, and the major automobile manufacturers have all employed outsourcing and have improved not only their cost competitiveness, but also their product quality (Willcocks and Lacity, 1995). This has been especially prevalent in the information technology (IT) area, where analysts estimate that 70 percent of the country's largest corporations have outsourced that area ("Outsourcing Megadeals," 1995).

Recently, several large government agencies have also planned to implement outsourcing for their computer systems: the General Services Administration (1997), the Federal Aviation Administration ("FAA will contract," 1997) and the National Aeronautical and Space Administration (1997).

"Generally, outsourcing has been fairly well accepted by the business and government communities...."

Generally, outsourcing has been fairly well accepted by the business and government communities; however, in a review of the literature on outsourcing, there have been several instances where outsourcing did not live up to the expectations of the agencies involved. This paper will review the outsourcing literature and lay out some considerations that should be taken into account when outsourcing is contemplated. Further, it will look at structuring the contract so that the pitfalls are mitigated.

Overview of Outsourcing

Outsourcing has had its successes and failures. Some of the successes in the private sector are described in a study done by The Outsourcing Institute (1997), which found that 30 firms realized a 9 percent average cost saving after outsourcing.

However, major outsourcing failures also exist. In 1995, for example, the Air Force awarded contracts to outsource the Aerospace Guidance and Metrology Center at Newark AFB, Ohio. The General Accounting Office (GAO) study on this effort found that privatization of the center would not generate the expected 20-30 percent savings first projected. In fact, the yearly savings were so minimal that it was expected to take upwards of 100 years for the Air Force to achieve that magnitude of savings (Concannon, 1996; GAO, December 1994).

Outsourcing Automatic Data Processing

Outsourcing ADP requirements and their support has proven to be very successful in private industry. For instance, in a study of 32 outsourcings, 22 were successful, and only four were unsuccessful (Lacity, Willcocks, and Fitzgerald, 1996). This study also came to the following conclusions:

- Senior decision makers need input from their computer experts in order to make outsourcings work.

- Internal departments should be allowed to compete with external vendors for the outsourcings.

- Shorter contracts (less than four years) are more successful than longer contracts.

Some of the principal ADP successes with outsourcing have been by SmithKline Beecham, which saved 24 percent on its network operating and management services costs through outsourcing (Hewlett-Packard, 1996). Their contract provided 24-hour service to keep the network up and running at 90 sites in 30 countries, and addressed corporate software applications such as e-mail, groupware, finance, sales, administration, and manufacturing data. Next, Hewlett-Packard, which manages 100,238 computer "seats" worldwide, achieved a 44 percent annual savings when they reorganized how computer operations were being maintained (Hewlett-Packard, 1997).

Tempering these successes, however, are specific situations in which ADP outsourcing has not been successful. One significant early failure was the Air Force Materiel Command's award of an $87 million firm fixed-price contract to design, develop, test, implement, operate, and maintain the Air Force Equipment Management System (Air Force Audit Agency, 1996) . This example emphasizes the importance of how one should view the contractor: as a resource for your organization, who should not be given free rein in decision making.

The contract for this Air Force system established specific performance and sizing requirements, and stated that the contractor was totally responsible for sizing and providing hardware and software architectures sufficient to satisfy the requirements, and that the contractor would upgrade the hardware and software as needed to satisfy performance requirements. As it turned out, the system that was developed by the contractor did not meet either the hardware or software requirements for the program. However, due to the program office not establishing and performing adequate and complete acceptance testing, and failing to identify these deficiencies before acceptance of the software, the Air Force ended up having to replace the hardware and software at an additional cost of $4.5 million.

"One of the most troubling studies about ADP outsourcing...indicates that only 31 percent believed that their outsourcings generated significant cost savings, with 69 percent disappointed in their outsourcing results."

One of the most troubling studies about ADP outsourcing was performed by Deloitte and Touche, in a survey of 1,500 chief information officers (CIOs) in the United States and Canada (1997), which indicates that only 31 percent believed that their outsourcings generated significant cost savings, with 69 percent disappointed in their outsourcing results. The survey highlights two major sources of dissatisfaction:

First, CIOs believed that they would achieve savings due to economies of scale or superior contractor resources, which did

not materialize, because the fixed-price contracts they entered into did not pass hardware, software, or personnel cost savings over time along to their customers. This finding is also supported by Lacity and Hirschheim (1993), and Lacity, Willcocks, and Fitzgerald (1996), who found that commercial contracts dealing with outsourcings have found problems with long-term contracts, so that the current trend today is to look at shorter time spans. Another problem with long-term contracts is that the organization changes over time, and the contract does not take into account the new organizational requirements.

"Gartner Vice President Mike Vargo said customers also do not realize that an outsourcing relationship takes more time and effort than they anticipated."

Second, customers complained that vendors were dishonest about the amount of subcontracting that would be used for the execution of their contracts. This became a problem when the subcontractor was unfamiliar with the contract provisions and customer expectations, or did not deliver the required services in the expected way. This concern was also voiced in an *Info World* article ("Managing your outsourcing," 1996), which reports that many firms that had outsourced their information technology functions were starting to reduce the scope or cancel parts of those efforts, because of lack of control over the vendors.

These results were similar to an earlier Gartner Group survey of 180 clients (1995) which found that only about 37 percent of the IT outsourcings were viewed as successful, either through improved performance (21 percent), or cost savings (16 percent); the remainder of the respondents gave either a mixed or too-early-to-tell response. Recent Gartner Group surveys have continued to show that gains from outsourcing have consistently fallen short of expectations by CIOs ("Outsourcing to the rescue," 1997). These surveys blamed the contracting process for not defining key issues and anticipated expectations. Gartner Vice President Mike Vargo said customers also do not realize that an outsourcing relationship takes more time and effort than they anticipated.

Government and Private Sector Differences

Much of the preceding research on outsourcings considers the private sector. Whether the government could achieve these same cost savings depends on how the differences between them would affect the enterprise. For example:

- Industry has tax incentives, investment write-offs, and other business-related savings that government activities do not have.

- Industry is not subject to the same oversight requirements concerning personnel reductions that government activities have, for, as mentioned earlier, most industry savings come from reducing the number of personnel performing the mission.

- Several companies cited in the above studies were small businesses, achieving savings due to economies of scale.

Government operations already rely on large purchase agreements or site licenses.

- Under long-term contracts, initial cost savings might be negated, if private-sector employees receive considerably higher wage increases than government employees over the life of the contract. This is fairly commonplace, where escalation clauses in the contract can raise contractor wages by as much as 10 percent a year in some cases.

These concerns are supported by Sam Kleinman's research at the Center for Naval Analysis (GSA Web Page, 1997), which reviewed 1,000 A–76 studies for government entities. Kleinman found that:

- Savings come from using fewer workers, not lower priced workers.

- Only 3 percent of government employees take jobs offered by the winning private sector firm.

- Government was found to be cheaper than private industry in 50 percent of the outsourcing studies, up from 30 percent several years ago ("OMB favors," 1997).

The GAO also looked at these previous A–76 outsourcings, and found savings (25 to 35 percent), but they were not so much due to moving the function out of the government as to competition. GAO also voiced several concerns about how successful these savings were to the government (GAO, March 1997):

- Savings estimates represented projected rather than realized savings.

- The costs of the competitions were not included.

- Where audited, projected savings have not been achieved.

Further, in looking at outsourcing military depot maintenance, GAO came to the conclusion that privatization of highly skilled technical maintenance may not generate the expected savings due to a number of factors, such as the specific technical nature of military equipment, the lack of competitive private sector companies that can perform these jobs, and that the reported savings on previous government outsourcings were overoptimistic, and did not reflect subsequent cost overruns, modifications, or add-ons (GAO, July 1996; GAO, December 1996; GAO, May 1997).

"...GAO came to the conclusion that privatization of highly skilled technical maintenance may not generate the expected savings due to a number of factors...."

Contracting Issues

When a government entity decides to try outsourcing, several contracting considerations must be addressed. Foremost among them is that even after the contract has been awarded there will be costs associated with maintaining that contract, especially if multiple subcontractors are selected to perform different functions

associated with the outsourced function. For instance, it could cost between 5 to 7 percent of the value of the contract to manage and oversee the contract. That would cover renegotiating the contract agreements, resolving disputes, and tracking the contract's performance (Scheier, 1996).

But these costs could vary depending upon the nature of the outsourcing: the more flexible the contract concerning the work to be performed, the more contract oversight will be required. Thus, there will be a tradeoff for the agencies involved, to make the contracts as flexible as possible to cover a broad range of needs and changing requirements, without overburdening them with contract oversight. However, this is a fine line, for if the service levels are tightly defined, one could find oneself paying high fees for incremental projects outside the defined scope of the contract. Some companies have reported that they have paid as much as 70 percent more than the original contract value in some areas (Lacity and Hirschhiem, 1993).

"...the more flexible the contract concerning the work to be performed, the more contract oversight will be required."

Next is the consideration of how the contract should be structured. For instance, the offeror's proposal should delineate what will happen to all of the assets under consideration: which ones the contractor will assume responsibility for, which ones will remain with the agency, and which if any will go to third parties. In addition, one should also consider if there are any intellectual property issues, such as software licenses (whether existing software can be transferred to the outsourcer), and ownership of self-developed software. Lastly, there are a number of measures that one can include in the contract to help determine whether the contractor is meeting the goals and costs projected for the outsourcing (Mylott, 1995; Rubin, 1997):

- response time (average or maximum);
- system availability (daily, by shift, by software application);
- downtime (daily, by shift, by software application, mean time between failures);
- turnaround time or schedule performance;
- operations cost measures (central processing unit hours, storage costs, total cost per hour, fixed cost, variable cost);
- communications cost measures (per hour, by distance, per line, per switch);
- services cost measures (per person, per application);
- performance reports;
- penalties for nonperformance;
- satisfactory performance (the organization's expectations of the vendor need to be clearly defined and discussed with the vendor);
- subcontractor approval rights (build these into the contract to specify that mission-critical projects or systems are handled only by the primary vendor); and

- value-based pricing and benchmarking, to periodically adjust to the marketplace, or to ensure that prices stay competitive. (An alternative to this would be to negotiate rates annually.)

A very good example of the process that one should go through is provided by Grupe (1997), who looks at the complete process of outsourcing a help desk function. He takes the reader through the decision process from precontracting to monitoring the contract after award. Likewise, Grover and Teng (1993) provide a systematic process to explore the decision on whether an information systems (IS) function should be outsourced. Generally, their recommendation is that if the process is a new or developing function, then it should probably remain in-house, unless it is not critical to the operation of the organization. In this same vein, Benko (1992) presents a process for determining what IS functions should be outsourced by looking at the question of whether a function should be outsourced or just restructured to improve its performance.

Recommendations

What does an organization need to do to achieve a successful outsourcing? The conclusions and recommendations that one can draw from the above studies follow.

First, the contract should include monitoring and performance measures as discussed above. This is also stressed by Aubert, Rivard, and Patry (1996), who recommend that in order to achieve benefits from outsourcing it is important to have enforceable and indisputable measures defined in the contract, so that one can easily make enforcement and cancellation decisions. In order for these measures to be relevant and useful in monitoring the contractor's performance, two steps must first be taken before the contract is let: One must develop a baseline of the current function that can be used as both information for the contractor and as a gauge to measure improvement against, describing its:

- practice and process;
- workload and costs; and
- time to perform the tasks.

Also, one must discuss with the contractor the best ways to monitor performance, and how frequently this should be done. Likewise, it would be beneficial to base the contractor's payments on the performance measures, to provide an incentive for the contractor not just to live up to the expectations, but hopefully to exceed them. Rubin (1997) also discusses this and presents a model that might be used to determine incentive pay for the contractor.

"Generally, their [Grover and Teng] recommendation is that if the process is a new or developing function, then it should probably remain in-house, unless it is not critical to the operation of the organization."

Second, the outsourcing should involve organizational changes to the way the previous function(s) operated. That is, in most cases, efficiencies from outsourcing come from changing the process, so that it is

more streamlined, and addresses the workload in a more organized manner.

The third recommendation is that the requirements for the outsourced function need to be focused and agreed upon by the players who require an interface with that function. This is a follow-on to knowing what you want to accomplish by outsourcing:

- How will outsourcing work with the existing organizational functions (will the new process address everyone's needs)?
- What will it do to reduce costs and or improve performance?
- How will it be implemented (is there a plan for when and how it will be implemented with the least disruption to the remaining offices)?

Aubert, Rivard, and Patry (1996) and Venkatraman (1997) touch on some of these considerations in their articles on taking a broad approach to decision-making concerning IT outsourcing.

Fourth, cost comparisons should be based upon the total life-cycle cost for the contract, since initial savings figures are generally not very reliable, and tend to escalate over the course of the contract.

Fifth, when a function is outsourced, look to see if it may be best to break it up into multiple contracts. This is counter to the current practice of omnibus contracting, but allows for better focus on the contracted function, and generally provides additional savings (much as in acting as one's own general contractor in building a house). This is a relatively new approach and has been tried by some major companies like British Petroleum and J. P. Morgan (Venkatraman, 1997)

Sixth and finally, the contract should either have a value-based pricing or benchmarking clause, or the length of the contract should be less than four years. This is important, especially in the ADP area, for the technology changes so rapidly that one needs to reassess, on a periodic basis, the mission and hardware requirements.

SUMMARY

In general, it would seem that outsourcing has the potential to generate savings, especially in the ADP area, but in order to achieve those savings, one must give considerable forethought to structuring the contract, monitoring the contractor's performance, and administering and providing oversight of the contract.

Next, contracting out any in-house activity assumes that the activity is inherently a "utility" function that can be performed by someone unfamiliar with the rest of the organization. Likewise, it assumes that a cookie-cutter approach can be used across offices that require an interface with that activity. For instance, while a number of alternative configuration setups can be used as the basis for fulfilling an activity's needs (i.e., different office equipment, software, and support), to the extent that those configurations do not meet the true needs of all the offices, the offices that are unique may not perform to their optimal ability.

Finally, several of the savings reported with private sector outsourcings represent cost avoidance savings versus real hard-dollar savings. For instance, some of the

private sector outsourcing studies, like those discussed by the Gartner Group above, count as savings the salaries of those individuals who can shift time back to performing their intended jobs, when technical support help desks are provided. The real amount of savings that this shifting of work accomplishes is uncertain, however, for it depends upon the salary of the workers performing those ancillary jobs, the salary of the help desk employees, and the degree that those work actions are actually transferred.

In conclusion, it would seem that while savings can be achieved by using an outsourcing approach to various business functions, the biggest gain with outsourcing seems to be with improved quality. Other gains would seem to be dependent upon the type of business function and its commonality; that is, the more common the activity, the more likely that savings would be achieved. Further, it would seem that outsourcings in private industry are more likely to achieve cost savings than those in the government, since industry has different tax and investment incentives than the government. Finally, in order to mitigate some of the problems that have occurred with previous outsourcings, each contract should include monitoring and adjustment mechanisms to gauge performance and rectify problems.

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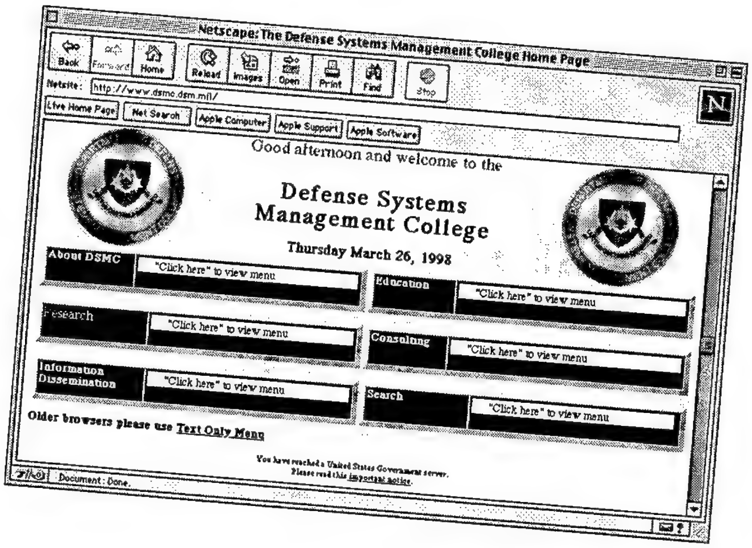

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❑ Short Course(s) _______________________________ (ex., ACQ101 98-1)